ABRAMS

Tests of Reinforced Concrete Beams Distribution of Stresses

Civil Engineering

B. S.

1905

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TESTS OF REINFORCED CONCRETE BEAMS

DISTRIBUTION OF STRESSES

BY

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THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE 1905

UNIVERSITY OF ILLINOIS

May 26, 1905

This is to certify that the following thesis prepared under the direction of Professor A. N. Talbot, Head of the Department of Municipal and Sanitary Engineering, by

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entitled TESTS OF REINFORCED CONCRETE BEAMS
DISTRIBUTION OF STRESSES

is accepted by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering

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TESTS OF REINFORCED CONCRETE BEAMS.

DISTRIBUTION OF STRESSES.

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The experiments described in the following pages are a part of an extensive series of tests undertaken by various engineering and private laboratories in the United States, under the direction of a Joint Committee appointed by four of the leading American engineering and technical societies. These tests are a part of the above series undertaken at the Laboratory of Applied Mechanics of the University of Illinois, as thesis work, by several members of the senior class in the course in Civil Engineering.

The purposes of these particular tests were three-fold:
(1) To determine the relation between the deformation of the reinforcing bars and the deformation of the adjacent concrete.
(2) To determine the effect of breaking the bond between the concrete and the reinforcing rods, i. e., of depending entirely upon normal pressure due to contraction of concrete in setting for the transmission of stress from concrete to reinforcing rods.
(3) To determine the effect of the tensile stress in the concrete below the neutral axis of the beam.

For each of these purposes, special beams were made which will be described in detail below. In order to make comparisons with normal or working conditions, plain concrete and simple reinforced beams were also made and tested.

The following divisions will be made: —I. Description of

Materials, II. Description of Test Pieces, III. Details of Tests, IV. Observed Data, V. Discussion.

I. Description of Materials.

For detailed description of materials, cement, sand, etc., and preliminary tests of same, reference may be made to thesis of Mr. E. T. Renner entitled Tests of Reinforced Concrete Beams, Effect of Release of Loads, presented June, 1905, where all such material for this entire series of tests was collected, in not being deemed necessary to incorporate same in each individual thesis.

All concrete used in the beams included in this report consisted of a mixture of one part cement, three parts sand and six parts broken limestone, measured by loose volume. Proportions of ingredients of concrete, amount of water, the method of mixing, etc., was same for all beams, in order to obtain, as nearly as possible, a uniform mixture.

All reinforcing rods were of 3/4 in. plain round steel rods. This steel was of a special variety of nominal elastic limit 60,000 lb. per sq. in. Several specimens tested to destruction in 100,000 lb. Riehle testing machine gave results about as follows:--

Ultimate strength 85,000 lb. per sq. in.
Elastic limit - - 52,000 " " " "
Coefficient of Elasticity - 29,400,000
Per cent. Elongation in 8 in. - - - 25

The appearance of the steel was very smooth, and glazed,

having almost the appearance of a turned surface.

II. Description of Test Pieces.

For more detailed description of manufacture of beams, etc., reference may be made to thesis of Mr. Renner, as mentioned above.

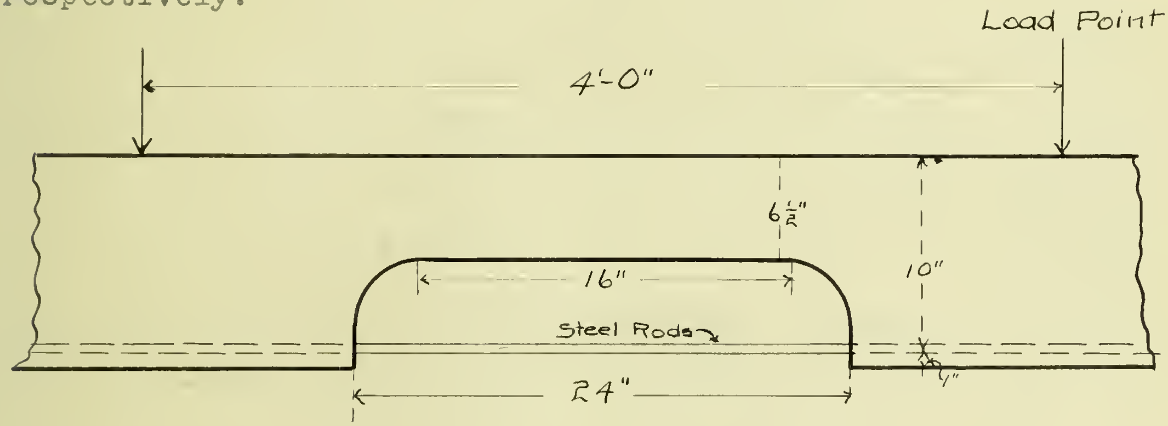
All beams were of same external dimensions, 8 in. x 11 in. x 13 ft. 0 in, and all reinforcing rods were placed symmetrically with respect to the longitudinal axis of the beam, in a horizontal plane, 10 in. below top of beam. Beams were made in ordinary knock-down wooden forms, placed on cement floor of laboratory. Concrete was deposited with shovels, in layers of about 3 in., each layer being thoroughly tamped. Forms were allowed to remain in place for about 48 hours. Beams remained in place on the floor for about one week, after which it was generally necessary to store them elsewhere. Beams were at all times exposed to the temperature of the room—about 70° F.

The manufacture of beams, where they differ from the general method, will be described in detail below, a summary of all beams being given at the end of this section.

Beams No. 49, 52 and 62 differed from the general form only in having an arch opening in the lower central part, exposing the reinforcing rods. The purpose of this opening was to admit a Riehle electric-contact extensometer, that deformations in steel under load, might be measured directly. Arch openings were made by placing a wooden form in bottom of outer form, consisting of two end blocks and a cover board, end blocks

having holes bored through them a little larger than the reinforcing rods, in order to allow them to pass through freely. This form was put in place by slipping end blocks over rods and placing cover plate, after which concrete was deposited and tamped. Forms for arch openings were easily knocked off when concrete had set and beams were lifted from the floor.

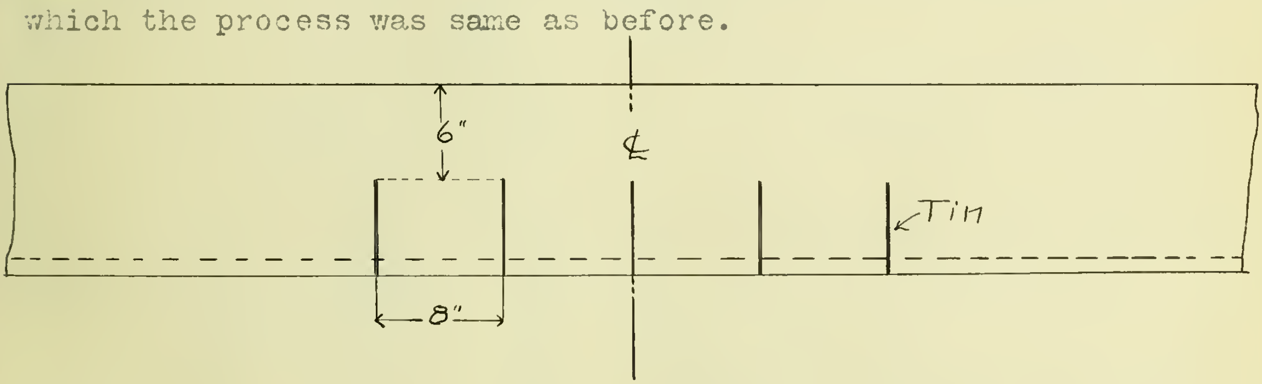
Sketch below shows dimensions for Beams No. 49 and 52. Beam No. 62 differed from these only in length of arch opening and depth of contracted section, which were 16 in. and 8 in., respectively.



Beams No. 51, 52 and 61 were peculiar in that artificial vertical cracks were formed in the bottom half of beams by imbedding pieces of tin in concrete at intervals of 8 in. on each side of middle of beam. Beams No. 51 and 52 had five such cracks, Beam No. 62 had 13. These tin partitions extended within 6 in. of top of beam and were made in three pieces for Beams No. 51 and 52, two being over reinforcing rods, bent at right angles and nailed loosely to the side of wooden form to hold them in place, and one filling space between and below rods, it also being nailed to wooden form. All pieces were covered with a coat of stiff lard-oil to prevent adherence of

concrete. Tins on top each extended beyond the center of beam for enough to lap a short distance, it being the intention to pull one out from each side. Beam No. 61 differed from above in that the piece of tin below rods was ommitted, it being found impracticable to remove tins as at first intended, and in that tins were wrapped in heavy drawing paper, which was separated from tin by a coat of same oil as used in Beams No. 51 and 52.

In Beams No. 51 and 52, lower pieces of tin were put in place in form, then a layer of about 1 in. concrete deposited after which rods were placed, passing through grooves cut for them in tins. Upper tins were then placed, when concrete was deposited in uniform layers of about 3 in. and carefully tamped between tins with a small cast iron tamper weighing about 10 lb. After concrete reached about 1 in. above top of tins, it was thoroughly tamped with heavier tampers. Beam No. 61 differed from above only in that about 1 in. of concrete was deposited, and rods put in place before tins over rods were placed, after which the process was same as before.



Sketch above shows arrangement of artificial cracks for Beams No. 51 and 52.

Beam No. 56 was made in same manner as simple reinforced beams except that the two reinforcing rods were wrapped in

oiled tissue paper. This paper was such as is used for wrapping butter, etc., and was obtained from a local butcher shop. It came in sheets about 8 in. x 11 in., was very thin and impervious to water. The entire sheets were wrapped around the rods, and lapped about 1 in., being held in place by small rubber bands at the laps. Care was taken in placing rods and tamping first layer of concrete that paper was not broken.

Beams No. 55 and 57 were simple reinforced beams, with 3 and 2 reinforcing rods respectively, and need no further comment.

Beam No. 65 was of plain concrete with no reinforcement.

Beam No. 67 was made same as simple reinforced beams except that rods were placed 10 in. from bottom of beam, instead of 10 in. from top, beam being reversed in testing. This beam was made by placing forms on a board as the floor was too rough to admit of placing forms on floor. This arrangement prevented escape of water as freely as before.

Table I. Summary of Beams.

Beam No.	Reinforcement No. Bars	Reinforcement Percent.	Age at Test, Days	Remarks.
49	2	1.11	60	24 in. Arch at middle, 5 in. high
51	3	1.52	59	5 tins, 8 in. apart
52	3	1.52	60	" " " "
53	2	1.11	61	Same as No. 49
55	3	1.52	59	Simple reinforced
56	2	1.11	59	Wrapped in oiled tissue paper
57	2	1.11	59	Simple reinforced
61	3	1.52	59	13 tins at middle, 8 in. apart
62	2	1.11	59	16" arch at middle, 3 in. high
65	none	none	59	Plain concrete
67	2	1.11	57	Beam made with rods 10 in. from bottom but reversed in testing

III. Details of Test.

All beams were tested with a span of 12 ft. between end supports, reinforcing bars being down. Age of beams at test was, as nearly as possible, 60 days, exact age being given in Table I, page 6. Load in all cases was applied equally at the 1/3 points of beam, i. e., at points 24 in. each side of middle of beam, this giving a uniform bending moment throughout the middle third of the beam, except for the weight of the beam itself. Loads were applied with the slowest speed of a 200,000 lb. Olsen testing machine, machine being stopped for readings generally at increments of load of 1000 lb. for reinforced beams. Loads recorded do not include weight of beam and apparatus, which amounted to about 1300 lb. Care was taken to avoid eccentric loading and the resulting eccentric stresses by giving an even bearing on the beam for loads and reactions and using roller bearings for all loads and reactions.

Deformations in beams were measured by means of Johnson extensometers, reading by vernier to .0001 in. One set of extensometers was placed symmetrically with respect to the middle of the beam in all tests, generally with a span of 42 in. between frames, which was sometimes changed to 54 in. In some tests, as Beams No. 49, 51, 52, etc., a second set of Johnson extensometers was placed on outer third of beam, 6 in. from reaction, with span of 36 in. These two sets of extensometers have been designated in tables below, pp. 44 to 60 as Inside and Outside extensometers, respectively. Extensometers were mounted on frames especially arranged for these tests.

Upper contact point was 1/2 in. below top of beam, and lower contact point 10 in. below top of beam in all cases. Extensometers of each set are numbered 1, 2, 3, and 4, No. 1 and 3 being top pair and No. 2 and 4 bottom pair in all cases.

For measuring deformations in steel in arch openings in Beams No. 49, 53 and 62, a Riehle electric-contact extensometer reading direct to .0001 in. was placed directly on one rod. The dials of this extensometer are referred to as A and B. Arrangement of apparatus is shown in accompanying photographs of tests at end of this paper.

Deflections were read in inches by means of a horizontal thread passing over nails attached to beam at center of depth over each support and held taut by a weight at one end, a scale being attached to middle of beam, over which thread travelled as beam deflected.

As a check on the above method a cathetometer, standing on the laboratory floor was used for reading deflections. The latter method was fully tested before it was relied upon, readings being taken on ends of beam to determine what the relative vertical motion of the entire beam was. It was found that there was a deflection in the tables of the machine of about 2 millimeters for a load of 12,000 lb. and as the deflection was a direct function of the load, and the load in few cases in these tests approached 12,000 lb., it appeared that the cathetometer readings were better than those obtained from the thread, since the individual readings are much more reliable.

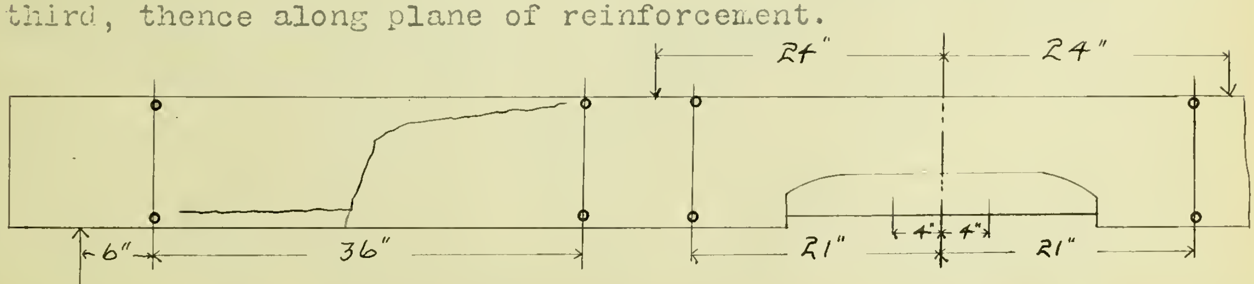
The maximum load was carefully observed in each case, and

as many readings as seemed practicable taken after the maximum was passed, in order to determine the behavior of beam beyond maximum load.

IV. Observed Data.

Under this head will be given a brief history of each beam, including its character before loading and its behavior during test. All original readings will be found in Tables I to XVII, pages 44 to 60.

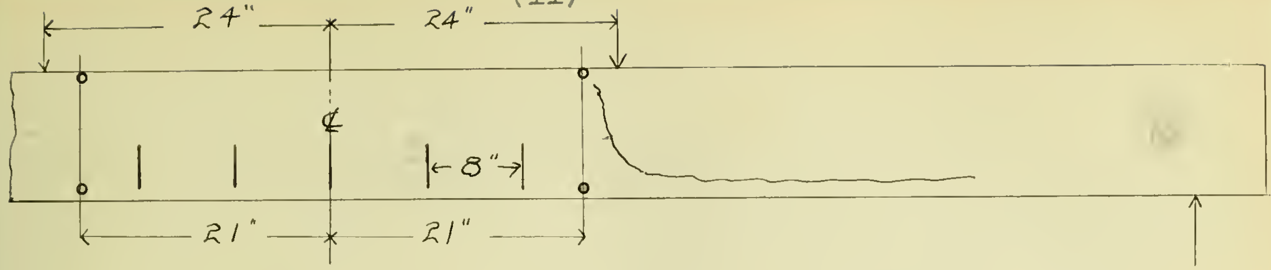
Beam No. 49. Load on this beam was run to 9000 lb. and then released, readings being taken at intervals of 1000 lb. each way, after which the load was again run up until beam failed. The purpose of this was to determine the action of the stress in the reinforcing bars under repeated load. At 8000 lb. a small crack appeared on the lower surface of the concrete, near one end of the arch opening, in the contracted section. As load was increased to 9000 lb. this crack continued to open, and gradually disappeared as load was released. Load was again run up without additional signs of failure, until beam failed suddenly at 11,300 lb. by shear-tension along diagonal and horizontal planes, beginning under the south load, and extending diagonally to a point about midway of the outer third, thence along plane of reinforcement.



(Above sketch shows manner of failure.)

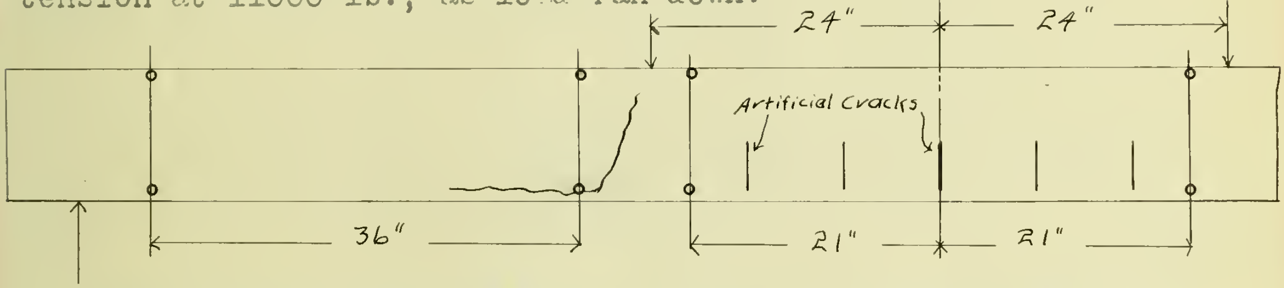
Beam No. 51. 3 3/4 in. rods; 5 artificial cracks, 8 in. apart at middle of beam. Two sets of extensometers were used. It was found impossible to remove the tins which had been placed in Beams No.51 and 52 after concrete had set long enough to take forms off. A preliminary test was made by imbedding similar pieces of tin in a cube made for the purpose. One piece was coated with oil only, and the other was wrapped in heavy oiled paper, as was described under the manufacture of Beam No. 61. These tins were easily removed from experimental cube with a pair of blacksmith's tongs, after about 30 hours, but it was not thought desireable to remove the forms from beams as soon as this. When the attempt was made after about 3 days, it was found impossible to remove tins from Beams No. 51 and 52, the tin being torn apart rather than breaking bond between concrete and tin.

There was a crack from fall at last tin to south, extending almost to top of beam. Mortar was observed to be broken under tins at 5000 lb. Crack appeared 3 in. outside of north load at 8000 lb. Crack at south load, 5 in. high at 11000lb. Crushing begins at top of beam at 11000 lb., after maximum of 11800 lb. had been passed. Diagonal and horizontal shear-tension crack begins just outside of north load, at 11000 lb., as load runs down, where failure occurs. Extensometer No. 4, inside set, being one of bottom pair, did not work properly, and the readings from No. 2 of same set were taken for mean readings.



(Above sketch shows method of failure of Beam No. 51.)

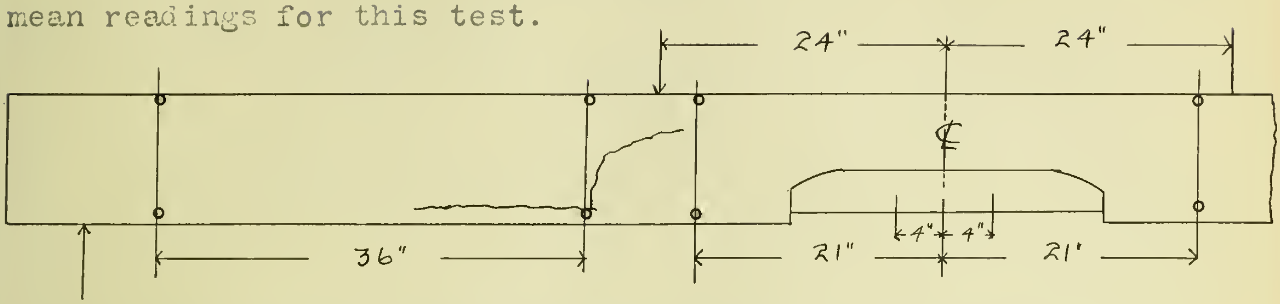
Beam No. 52. Same as Beam No. 51, which see for remarks concerning tins. Crack appeared below middle tin at 6000 lb. Crack appeared at bottom, 6 in. outside of south load at 7000 lb. This crack was 7 in high at 14000, lb., and 8 in. high at maximum of 14970 lb. Crushing begins on top of beam at 12000 lb., after maximum load was passed. Beam failed by diagonal shear-tension at 11000 lb., as load ran down.



(Above sketch shows method of failure of Beam No.52.)

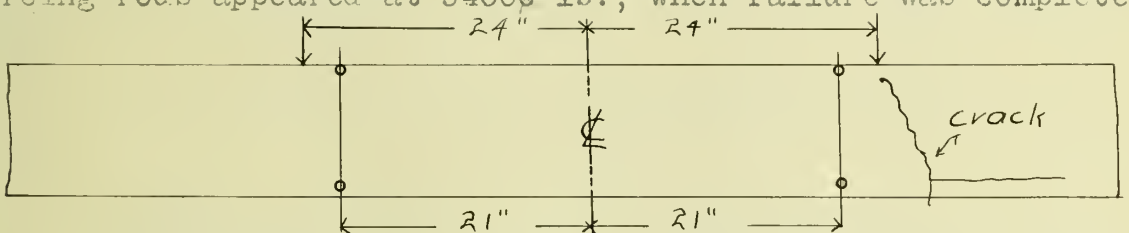
Beam No. 53. 2 3/4 in. rods; Arch opening 26 in. long and contracted section 6.5 in deep. Three sets of extensometers were used, one at middle of beam, one on outer third, and one on steel rod in arch opening. A minute crack appeared at south end of arch opening,,on lower surface, in contracted section at 6000 lb. Diagonal crack appeared under south load at 7000 lb. where failure occurred by diagonal and horizontal shear-tension, as load ran down, after the maximum load of 8000 lb. had been passed. No other cracks appeared, and no crushing on top was observed. Extensometer No. 2, inside set was not working

satisfactorily, and readings of No. 4 of same set were taken as mean readings for this test.



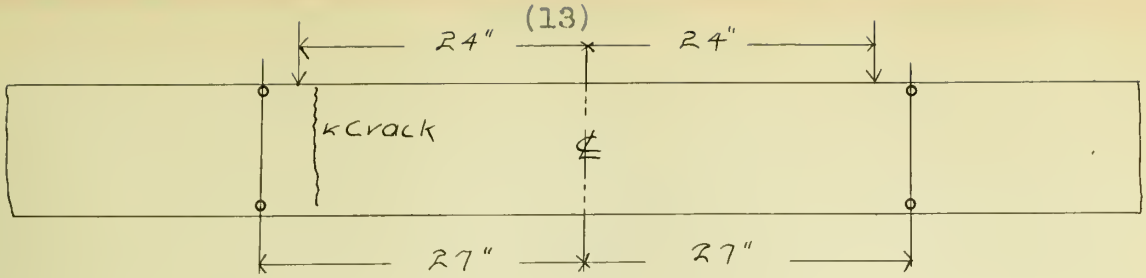
(Above sketch shows manner of failure of Beam No. 53.)

Beam No. 55. 3 3/4 in. rods; simple reinforced. One set of extensometers were used, on middle of beam. A vertical crack appeared outside of north load, 5.5 in. high at 8000 lb. Above crack, 7 in. high at maximum load of 9950 lb. Crushing begins just outside of north load at 5400 lb., after maximum load had been passed. Horizontal crack along plane of reinforcing rods appeared at 5400 lb., when failure was complete.



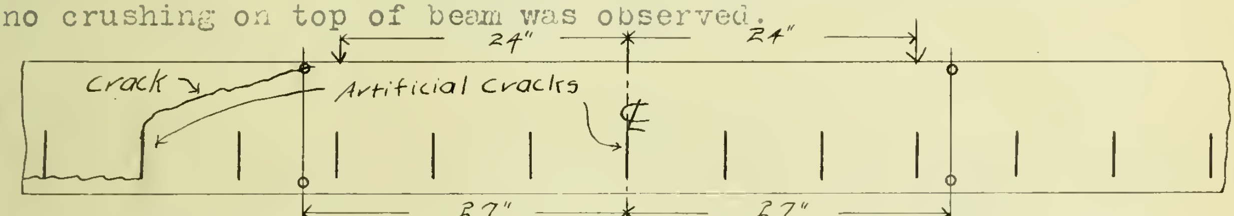
(Above sketch shows manner of failure of Beam No. 55.)

Beam No. 56. 2 3/4 in. rods; rods wrapped in oiled tissue paper. One set of extensometers used. Beam was broken in fall at point 2 in. inside of south load. Crack was about 1/8 in. wide when load was applied. Above crack continued to open as load was applied. Crushing on top of beam occured at south load at maximum load of 860 lb., after deflection of 3.8 in. Concrete was removed from each end of one rod, in order to observe whether rods had slipped. Rod was found to have slipped about 3/4 in. at end nearest which beam broke.



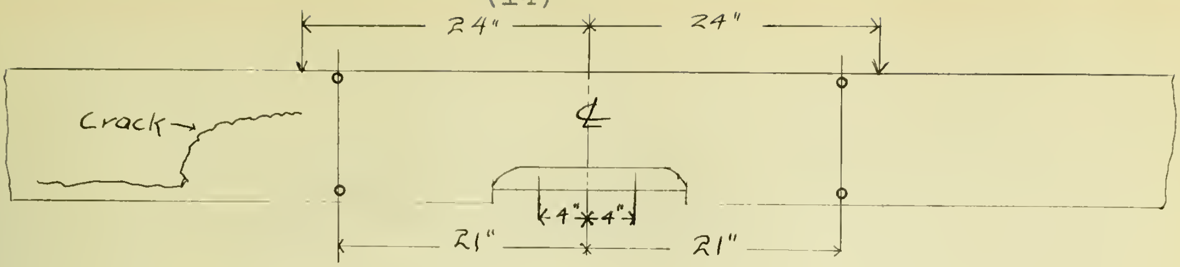
(Sketch above shows manner of failure for Beam No. 56.)

Beam No. 61. 3 3/4 in. rods. Beam same as No. 51 and 52, except that 13 tins were used, 8 in. apart. One set of extensometers was used. Minute cracks appeared under tins at 5000 lb., 1.5 ft. north of north load. Above crack within about 3 in. of top at maximum load of 6000 lb. As load runs off, crack continues to open, and failure occurs by shear-tension at this point. Mortar below rods was not broken elsewhere, and no crushing on top of beam was observed.



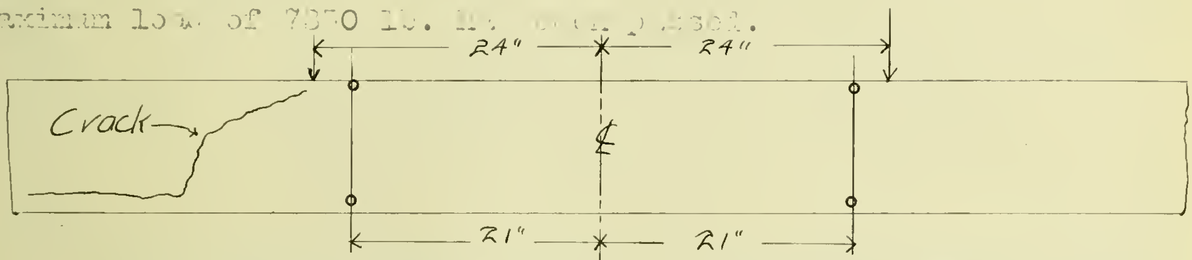
(Above sketch shows manner of failure for Beam No. 61.)

Beam No. 62. 2 3/4 in. rods. Arch opening, 16 in. long, with contracted section 8 in. deep. One set of extensometers. Crack at north end of arch, entirely across lower surface, in contracted section. Crack under south load, outside of extensometer span, 4 in. high at 6000 lb. Crack 1 ft. outside of north load 1/2 way up, at 8000 lb. Crack at south end of arch, in contracted section, appears at 8000 lb. Crack outside of north load continues to open as load is applied, where failure occurs by horizontal shear and tension, after maximum load of 8100 lb. had been reached.



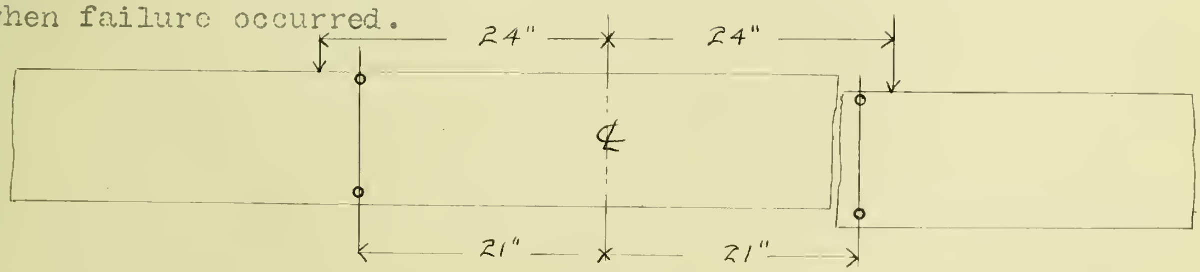
(Above sketch shows manner of failure for Beam No. 62.)

Beam No. 57 2 3/4 in. rods. Plain reinforced. One set of extensometers was used. Minute cracks appeared at intervals along the bottom of beam at 6000 lb. Diagonal crack appeared outside of south load, where failure occured by diagonal and horizontal shear and tension at load of 4500 lb., after maximum load of 7370 lb. had been passed.



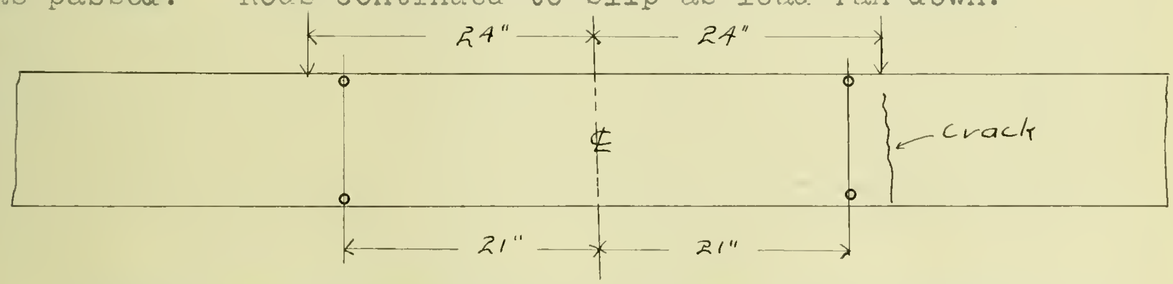
(Above sketch shows method of failure for Beam No. 57.)

Beam No. 65. Plain concrete. One set of extensometers. Beam had not been moved from its original position until time of test. Load was applied with slowest speed of testing machine, and readings taken at intervals of 200 lb., until beam failed suddenly 1260 lb. by vertical crack near middle. Beam was broken in several pieces by fall of about 1 in. on blocking when failure occurred.



(Above sketch shows manner of failure for Beam No. 65.)

Beam No. 67. 2 3/4 In. rods. This beam was made upside down and reversed in testing. One set of extensometers used. Crack appeared under north load, and extended 1/2 way up beam at 4000 lb. Numerous minute cracks appeared in middle third at intervals of about 6 in. or 8 in. at 4000 lb. Cracks just outside of each load continued to open and one at north load had reached within 2 in. of top of beam at maximum load of 8600 lb. Crushing begins under north load at 6600 lb., after maximum load had been passed. Failure occurred by vertical crack at north load and slipping of rods. North end of beam was broken away, to expose rods, and it was found that rod had slipped about 3/4 in. up to load of 6600, after maximum load was passed. Rods continued to slip as load ran down.



(Above sketch shows manner of failure for Beam No. 67)

V. DISCUSSION.

It was soon observed that the steel for these tests was not the best for the purpose, on account of the polished surface it presented. When the surface of the concrete around reinforcing bars was examined, it was found to be as smooth as polished granite, and gave other evidences that the bond between the concrete and steel was not as good as had been expected, when this high steel was used. Evidences of the premature slipping of the reinforcing rods are abundant, both from the curves, and from actual observations on the bars in place, as was noted under Observed Data, page 12, under discussion of Beams No. 56 and 67. Evidences of slipping, as shown by curve may be found in Beam No. 53, Plates 10 and 12. On account of the unreliability of the bond between the concrete and steel, some of the results of these tests may be very erratic.

The manner of failure of these beams, and the low unit stresses developed, together with the absence of crushing on top of beam until long after the maximum load had been passed, seems to emphasize the fact that there was not the proper bond between the concrete and steel. It is seen from the curves that, as the load was applied there was the usual relation between deformations and deflections until maximum load was reached, which marks the point where bond between concrete and steel failed, after which the deflection curve becomes almost horizontal.

Generally these beams failed by diagonal shear-tension just outside of the load point, long after the maximum load had been passed. The presence of the arch openings in the beams did not have any appreciable effect on the behavior of the beams. The artificial cracks served, in some cases as starting points for other cracks, where failure ultimately occurred.

The curves for these tests present the same general characteristics that have been noted in former tests of reinforced concrete beams. Referring to the first purpose of these viz., to determine relation between deformation in steel and deformation in adjacent concrete, we find that in Beam No. 49 the steel curve is of identically the same form as that for the adjacent concrete, but the latter shows a systematic gain over former, for repeated loads, probably due to the slipping of the rods, while in Beams No. 53 and 62, the deformation curves are remarkably similar up to a unit deformation of about .00055, corresponding to a stress of about 16000 lb. per sq. in. in steel. In Beam No. 49, the only case where load was repeated, it will be noted that steel deformation curve returns to the original zero, while the adjacent concrete does not return, but shows a permanent gain of about .00013, per unit length. This must be due to a set in the beam itself, as the same characteristic shows in the deflection curve on Plate 1, page 44.

The stress in steel for Beams No. 49, 53 and 62, as given by equating bending moment to resisting moment, and by taking

Unit deformation in steel itself, and by taking unit deformations in adjacent concrete, as deformation of steel, are given below, using coefficient of elasticity of steel as 29400000.

Beam	Load	Stress in Steel		
		Moments	Elongations	
No.	Considered		Steel	Concrete
49	11000	35800	31200	35750
53	8000	27000	24360	26100
62	8000	27300	25400	22600

This shows a fair agreement of the different methods of calculating stresses in the steel reinforcement.

The beams made for testing the effect of tensile stress in the concrete below the neutral axis, did not serve the purpose as well as was hoped. It was not certain that cracks were left in Beams No. 51 and 52, though the curves are remarkable for the absence of the "hump" which has been accounted for by assuming that this was the point where the tensile stress was transferred from the concrete to the steel. Beam No. 61 exhibited a hint of the "hump", but not so distinct as usual in other curves of this series. The tins were removed from this beam, but to do so it was necessary to remove the forms sooner than usual, and the concrete might have been injured by the too rapid evaporation of the water in a warm room.

The result of breaking the natural bond between the concrete and the steel was to reduce the beam to nothing more than a

plain concrete beam, except for the stiffness of the rods themselves, as there was no appreciable grip on the rods due to the normal pressure of the concrete from contraction in setting. The paper probably acted as a cushion to take up whatever deformation there was due to contraction in setting without exerting any pressure on the rods. Other test pieces made from the same concrete, with the rods wrapped in similar paper, for adhesion tests, showed that there was no appreciable bond between the concrete and the steel.

It is considered unfortunate that a different steel was not used for these tests, as it appears that more definite results might have been obtained, if the full strength of the concrete or steel could have been developed. However, it seems to be evident that the relation between the deformation of the steel and the deformation of the adjacent concrete is very close in the absence of slipping of the rods. Also that the formation of artificial cracks gives a closer relation between the deformations of the upper fiber and the steel, seeming to indicate that the unit deformation in the steel is increased under small loads by the presence of the cracks. The method of investigation employed indicates that the grip on the reinforcing rods due to the contraction of the concrete in setting, is a negligible quantity.

The principal results of these tests are given in Table page 21. The maximum load, amount of metal and several calculated values are given. Bending moment is that due to applied load at maximum or nearest load below maximum, at which reliable readings were taken. This load is also given in column headed "Load Considered". k in column headed "k d" is ratio of depth of neutral axis below top to effective depth of beam. d is effective depth of beam, or 10 in. in this case. Moment arm = d(1 —.36k), making the usual assumption that compressive stress in concrete above neutral axis varies as the ordinates of a parabola.

DATA AND CALCULATED RESULTS FOR BEAMS

Beam No.	No. Rods	Amount of Metal Sq. In	Maximum Load	Load Considered	Stress in Steel Lb.Sq.In	k d In	Moment Arm	Bending Moment
49	2	.88	11300	11000	35800	4.5	8.38	264000
51	3	1.33	11800	11800	27300	5.6	7.90	283000
52	3	1.33	14970	14970	33400	5.3	8.09	359500
53	2	.88	8000	8000	27000	5.3	8.09	192000
55	3	1.33	9950	9950	23200	6.0	7.60	233000
56	2	.88	860	860	3080	4.1	8.52	23100
57	2	.88	7350	7000	23100	4.8	8.27	168000
61	3	1.33	6600	6600	14800	5.2	8.13	158500
62	2	.88	8100	8000	27300	5.6	7.90	192000
65	---	----	1260	-----	-----	---	----	27800
67	2	.88	8600	8000	25500	4.0	8.56	192000

All reinforcing rods were of 3/4 in. round, high steel.

The term k d, where k is ratio of depth of neutral axis from top of beam, to effective depth, is equal to 10 x (percent depth of neutral axis) since effective depth of beam is 10 in.

Moment arm = d(1 —.36k).

EXPLANATION OF CURVES.

Curves were plotted with applied loads as ordinates and unit deformations and deflections as abcissae. Curves designated "Upper Fiber" refer to upper fiber of concrete; those designated "Steel", give deformations in steel under the usual assumption that deformation of steel is same as that of the adjacent concrete. These deformations were determined graphically by finding the total deformations from the extensometer readings and dividing by the extensometer span.

Curves for upper fiber and deflections are given in black ink and those for steel in blue, in all cases. In case of plain concrete beam, curves are plotted for upper and lower fibers. The various positions for the neutral axis are plotted in percents of the effective depth of the beam below the top. Neutral axis was located graphically under the usual assumption that a plane section before bending remains a plane section after bending.

No curves were plotted for Beam No. 56, as only about three sets of reliable readings were taken, and beam was broken before testing.

PLATE I.

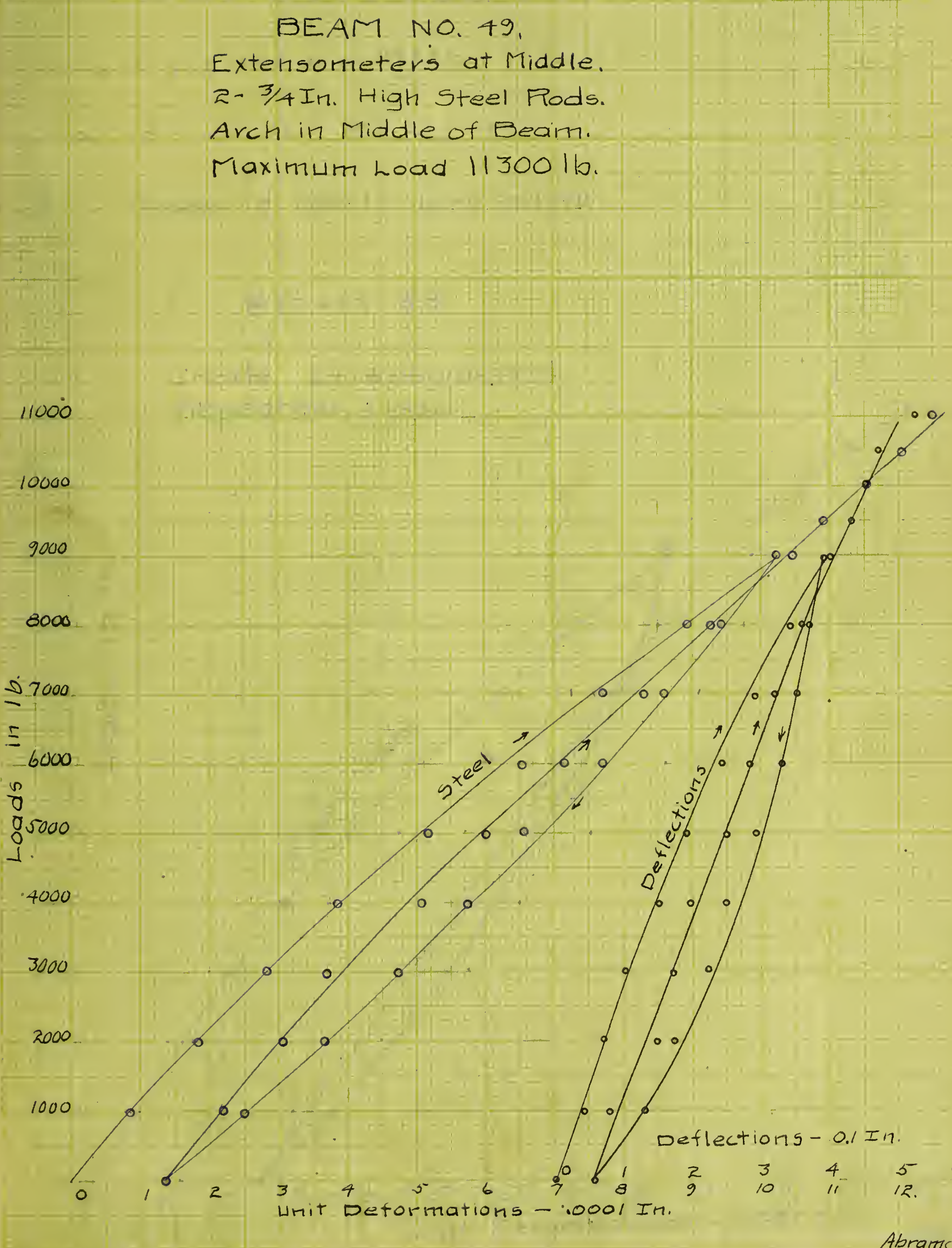
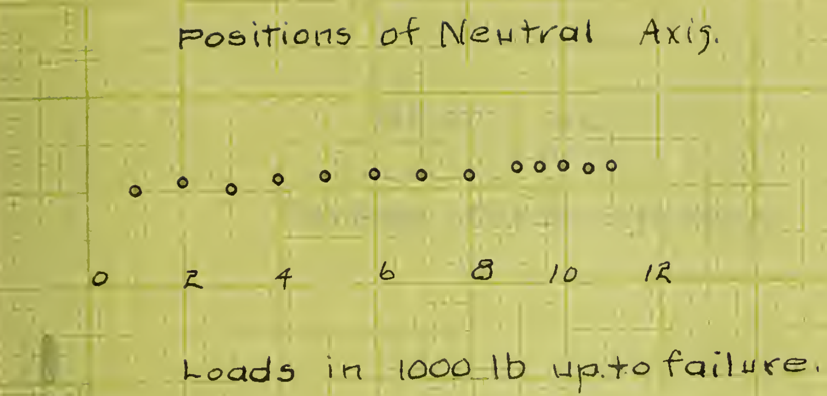

BEAM NO. 49.
Extensometers at Middle.
2- 3/4 In. High Steel Rods.
Arch in Middle of Beam.
Maximum Load 11300 lb.
Loads in lb.
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
Steel
Deflections
Deflections - 0.1 In.
0 1 2 3 4 5
Unit Deformations - .0001 In.
0 1 2 3 4 5 6 7 8 9 10 11 12
Abrams.

PLATE 2.



BEAM 49.

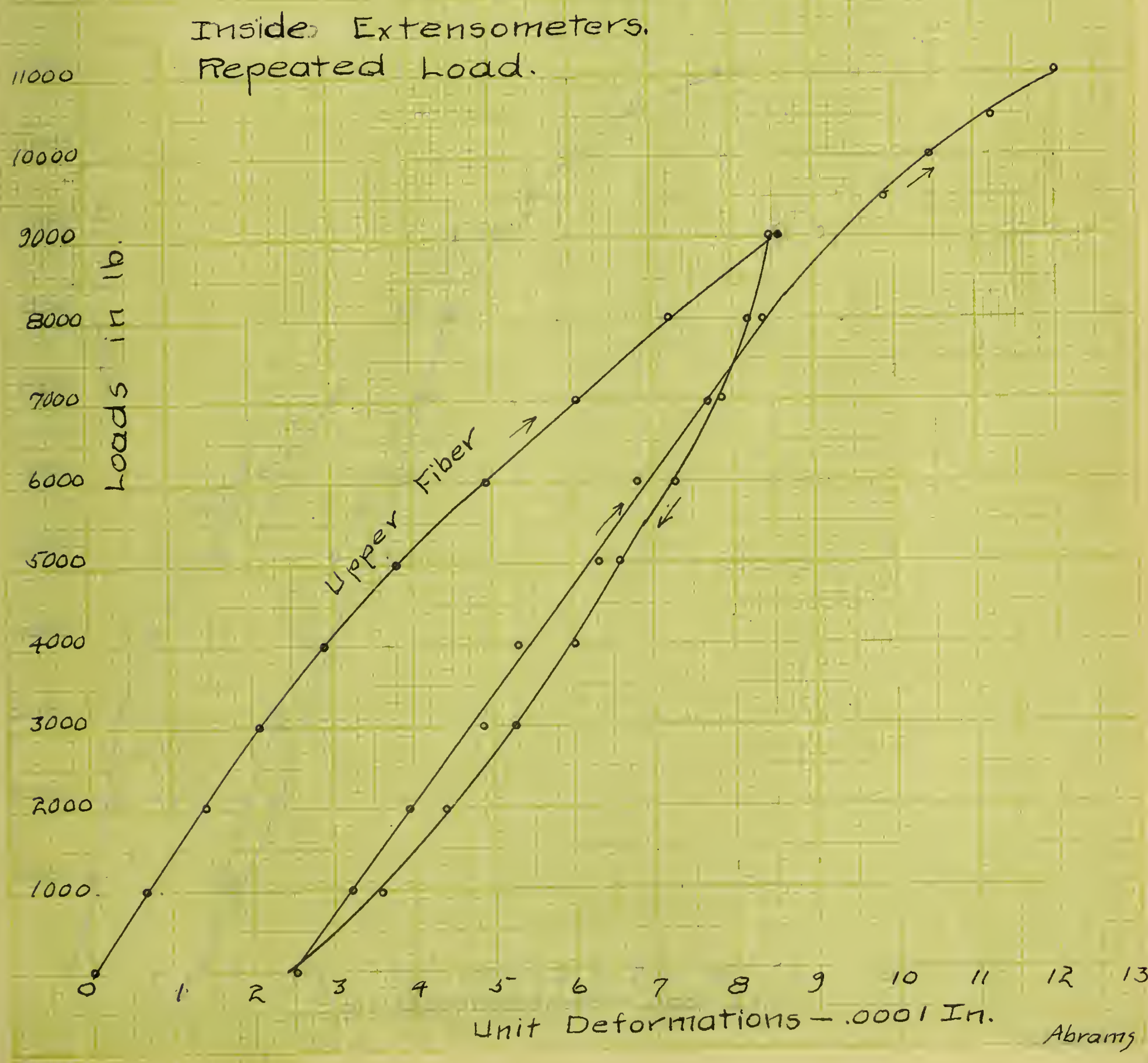
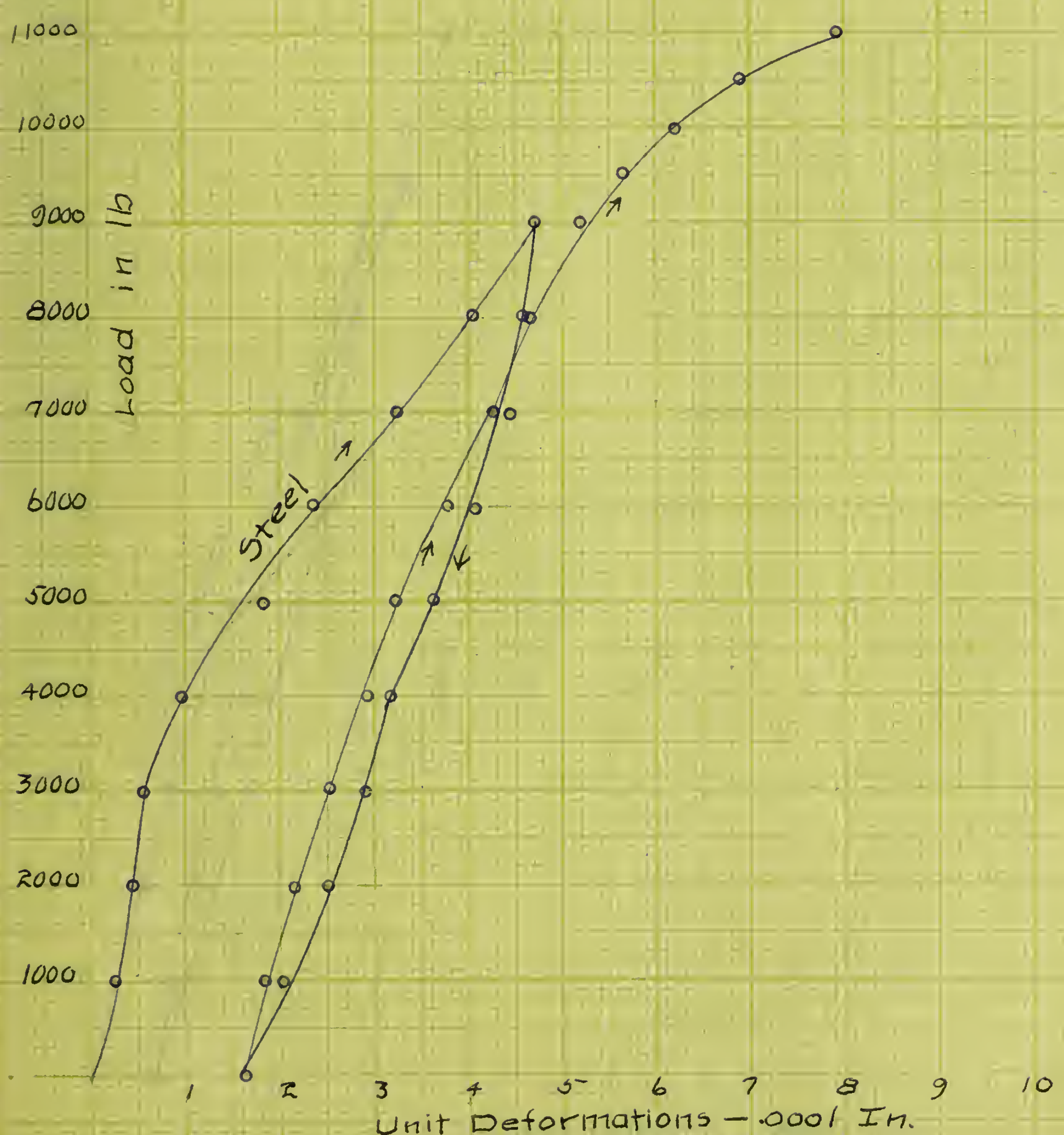


PLATE 3.

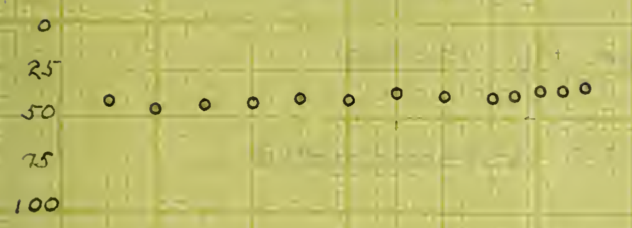
BEAM NO. 49.

Outside Extensometers.



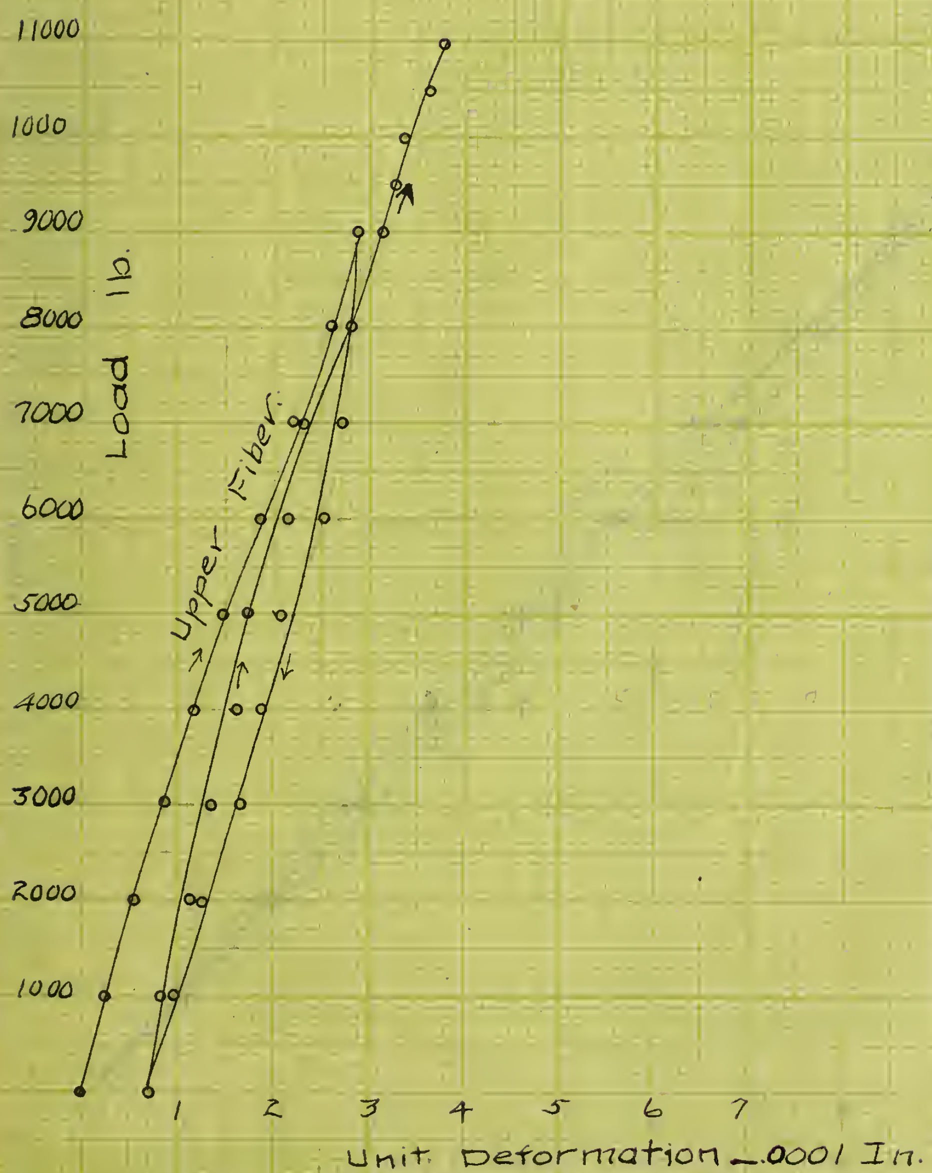
Abrams

PLATE 4.



BEAM NO. 49.

Outside Extensometers



Abrams

PLATE 5.

BEAM NO. 49.

Extensometer on Steel Rod.

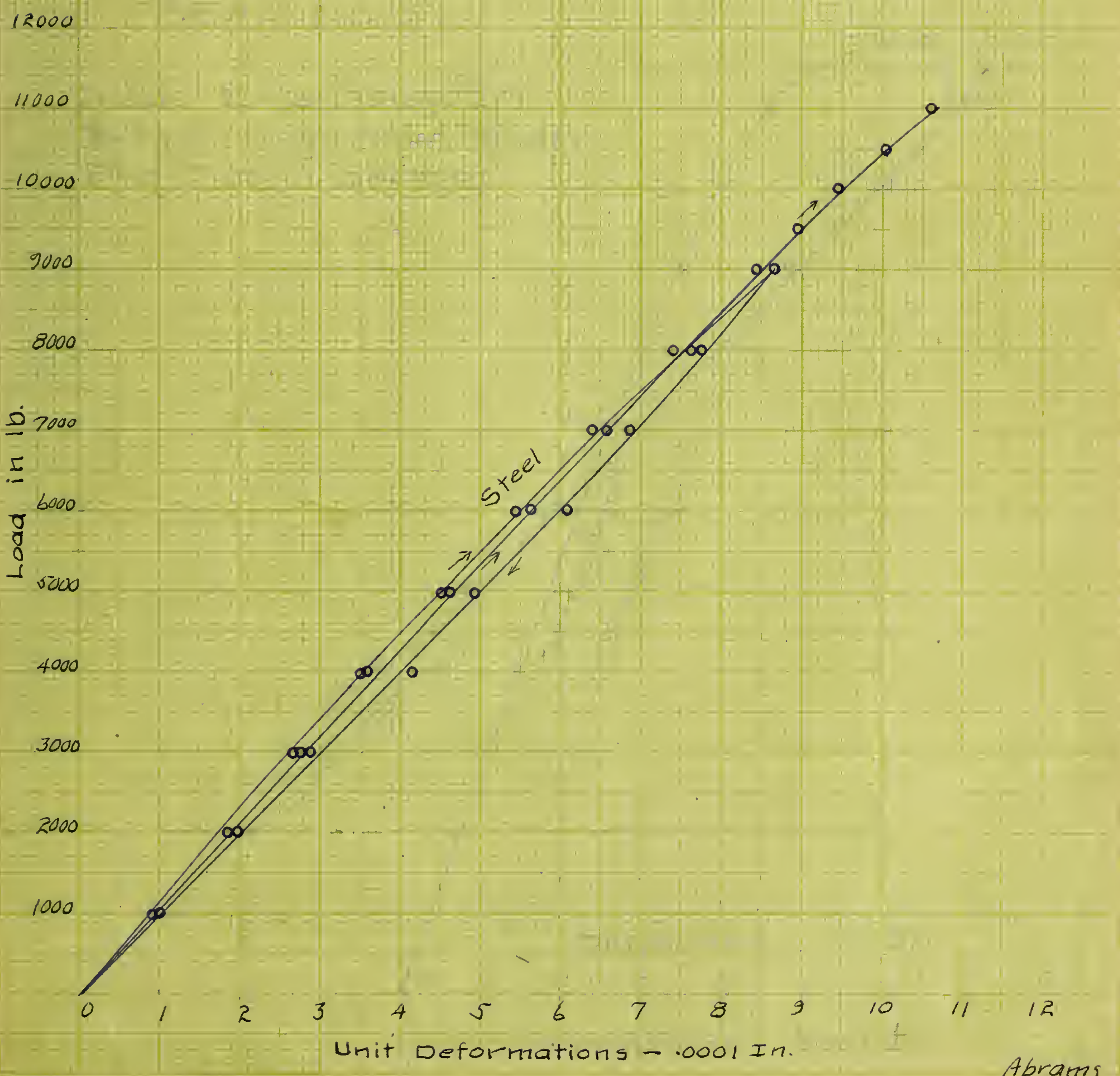
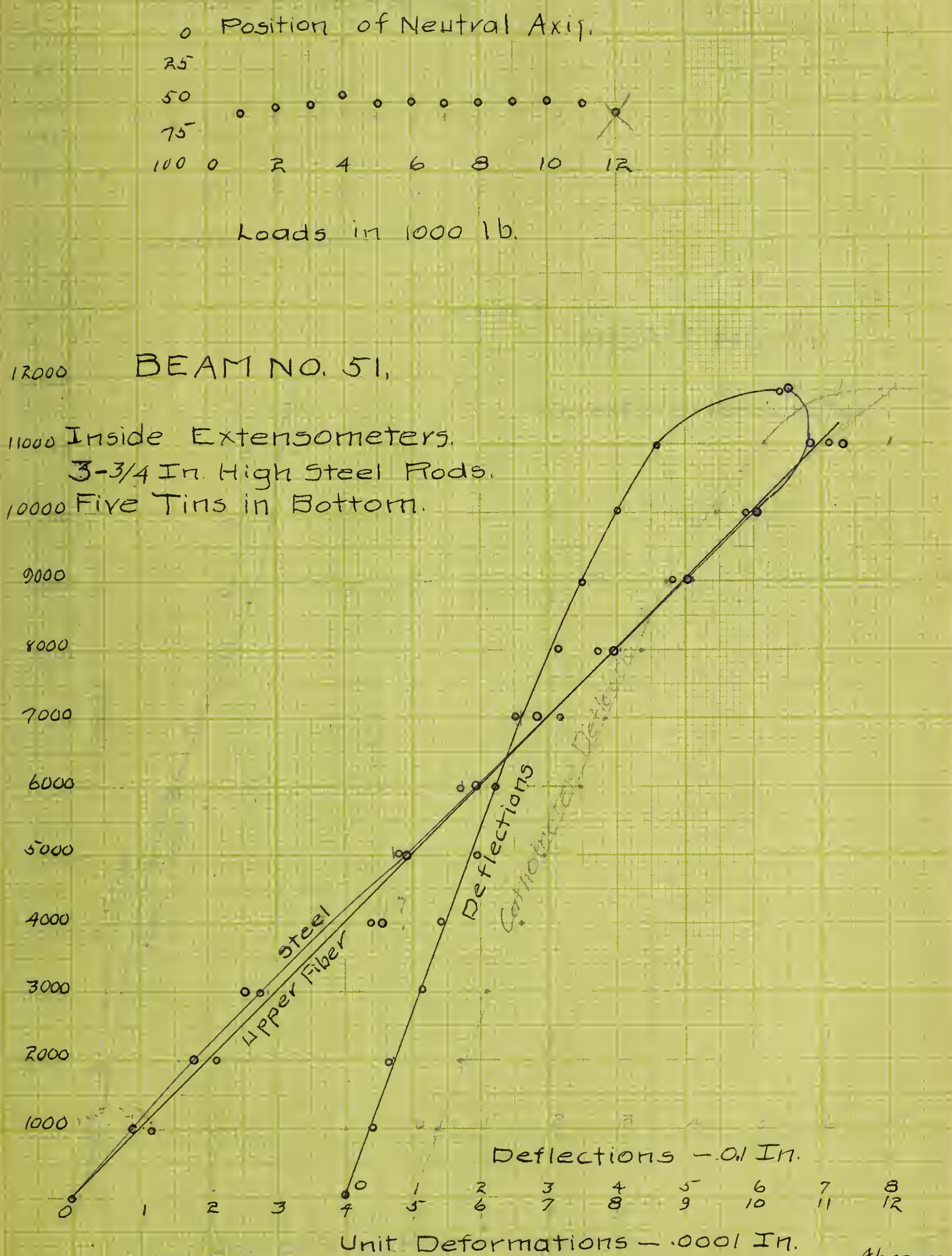


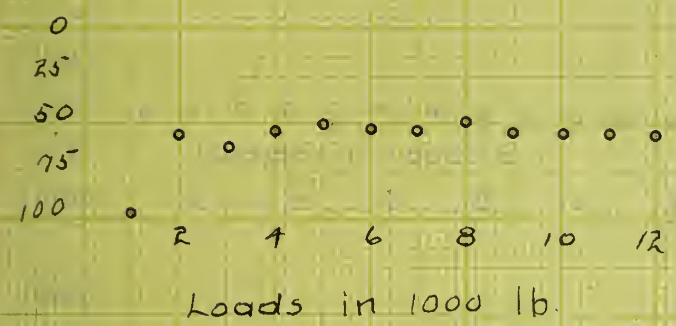
PLATE 6.



Abrams

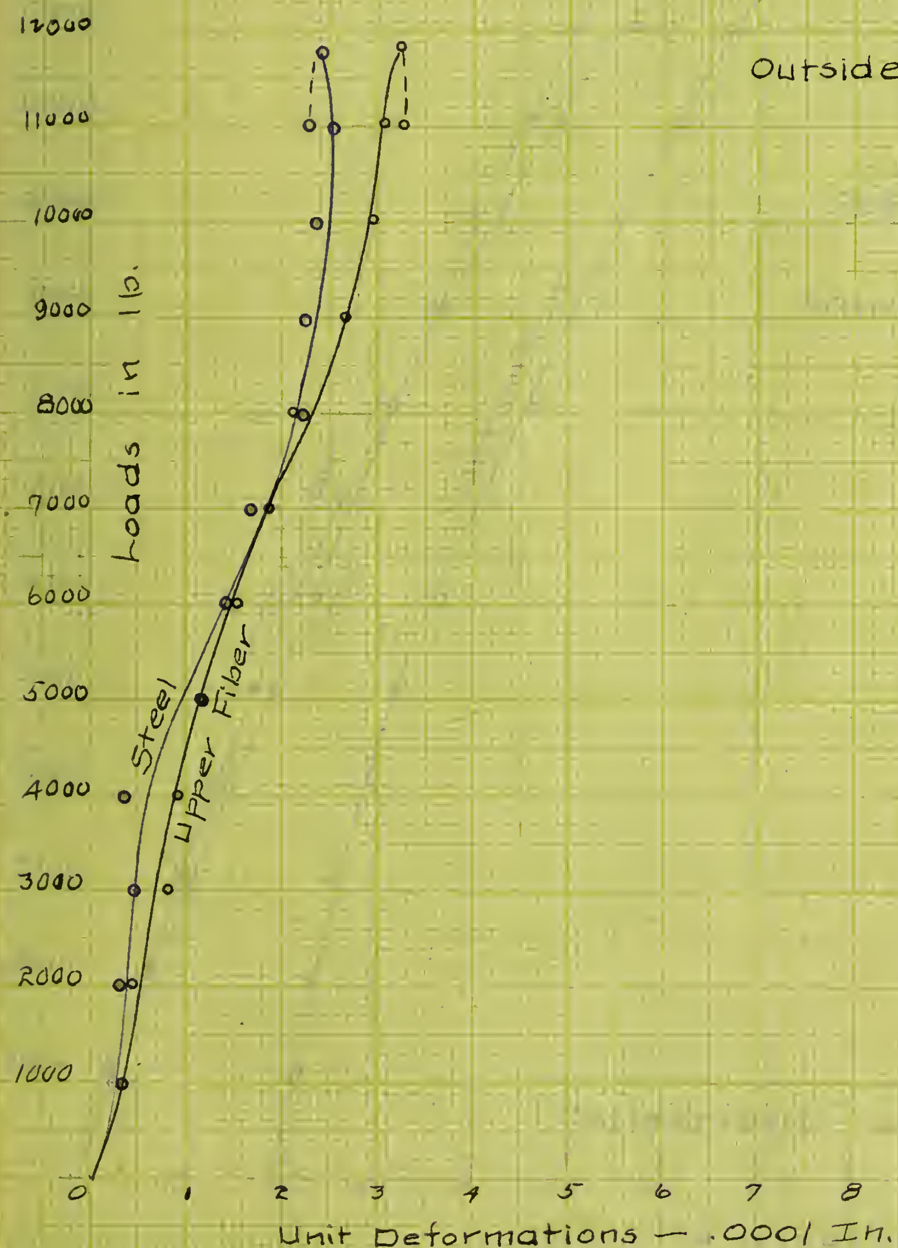
PLATE 7.

Positions of Neutral Axis.



BEAM NO. 51.

Outside Extensometers.



Abrams

PLATE 8.

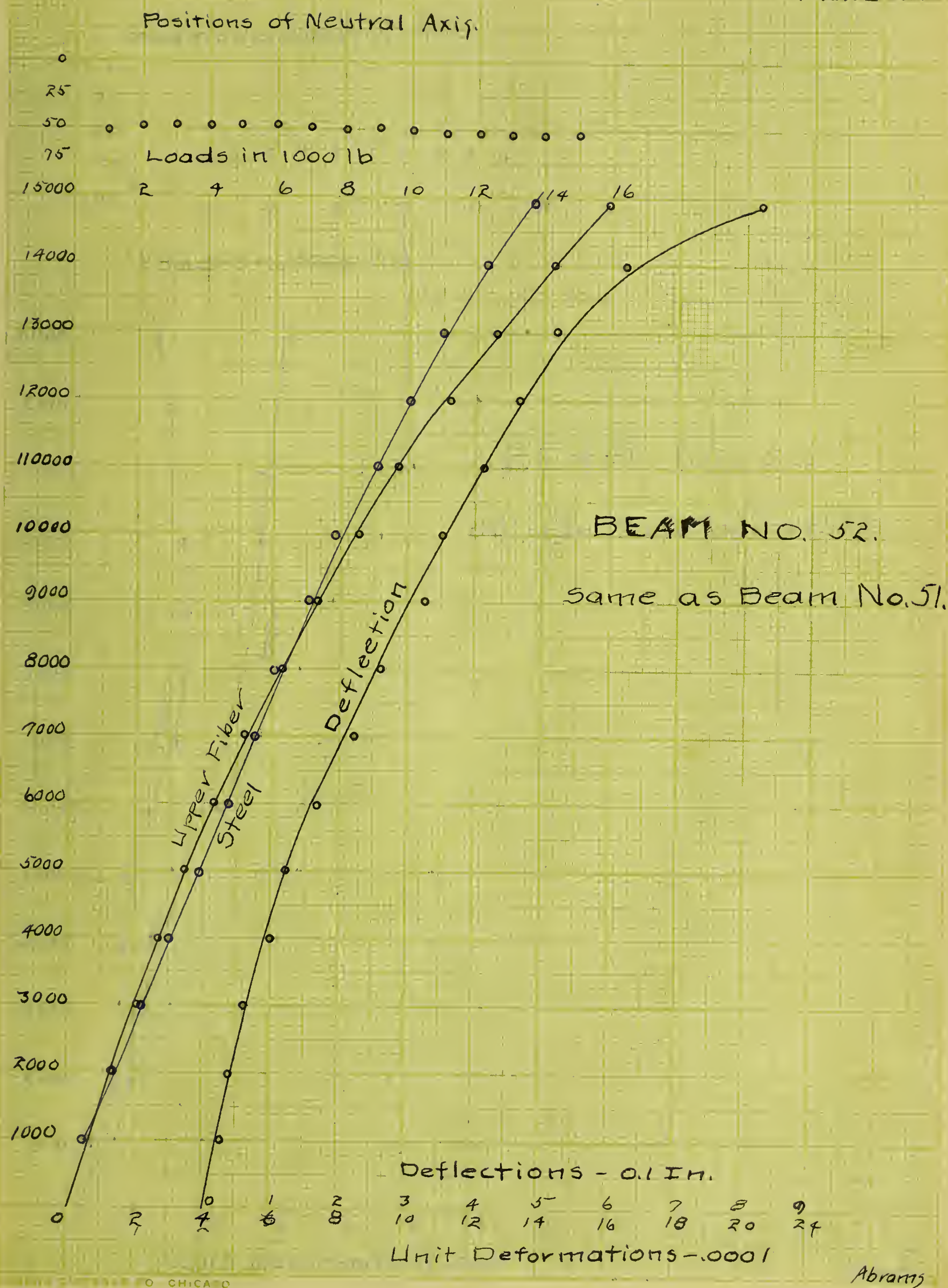
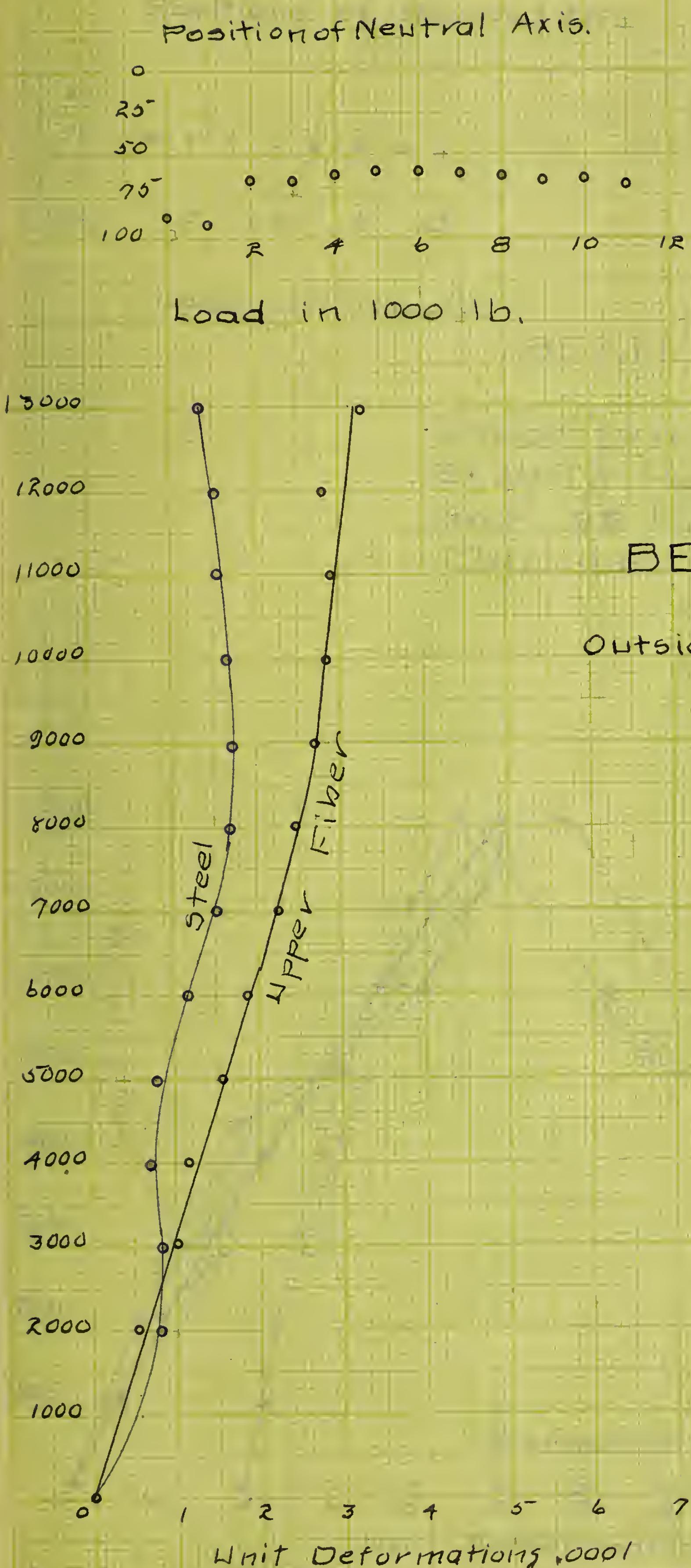

Positions of Neutral Axis.
0
25
50
75
Loads in 1000 lb
15000
14000
13000
12000
110000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
2
4
6
8
10
12
14
16
BEAM NO. 52.
Same as Beam No. 51.
Upper Fiber
Steel
Deflection
Deflections - 0.1 In.
0 1 2 3 4 5 6 7 8 9
0 2 4 6 8 10 12 14 16 18 20 24
Unit Deformations - .0001
Abrams

PLATE 9.

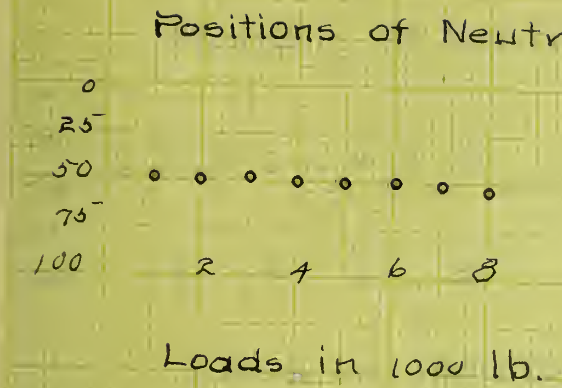
BEAM NO. 52.

Outside Extensometers.



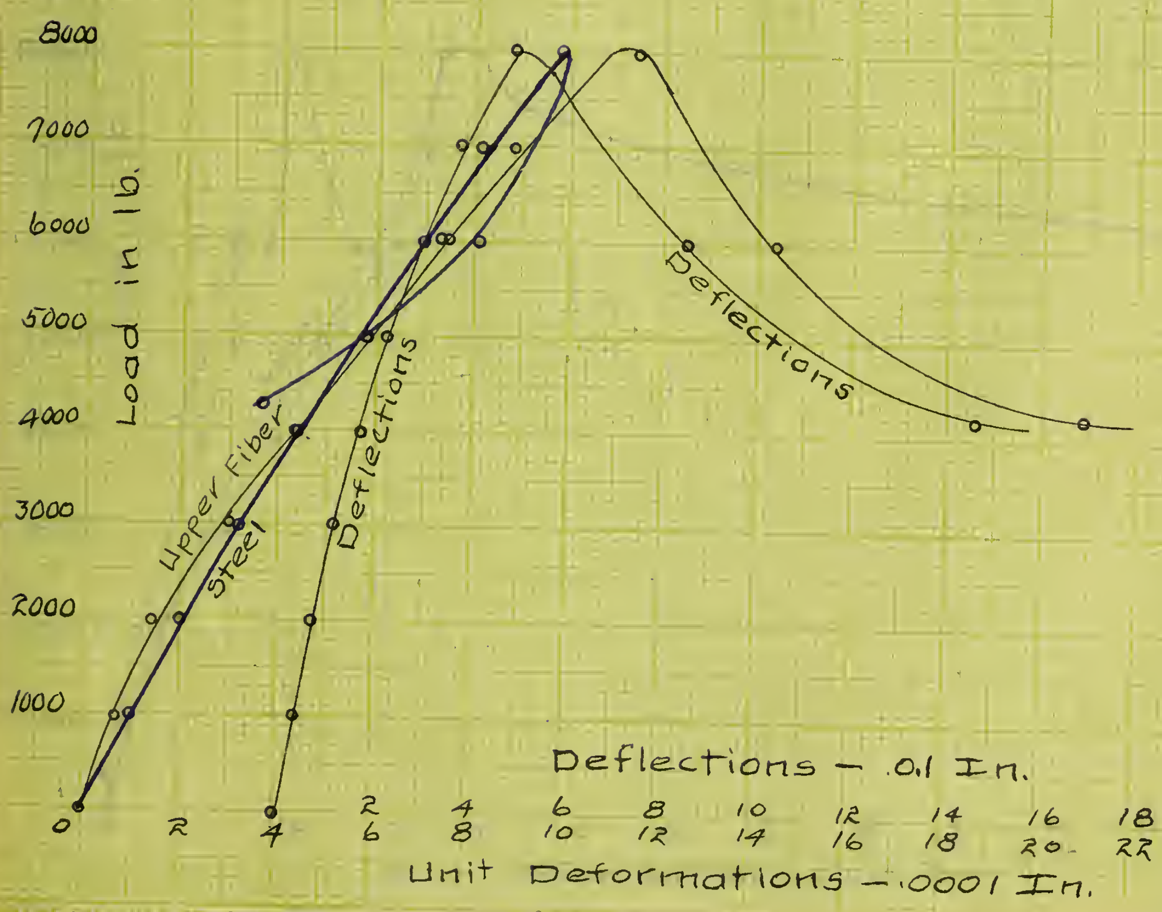
Abrams

PLATE 10.



BEAM NO. 53.

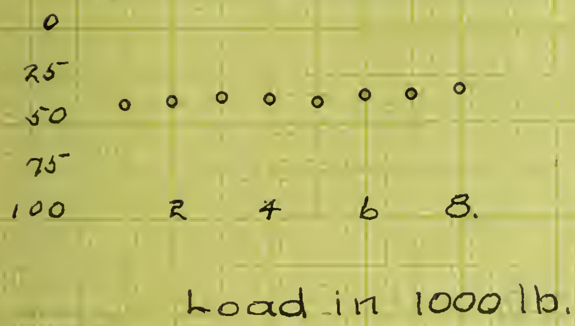
Inside Extensometers.
2-3/4 In. High Steel Rods.
Arch at Middle.
Maximum Load - 8000 lb.



Abrams

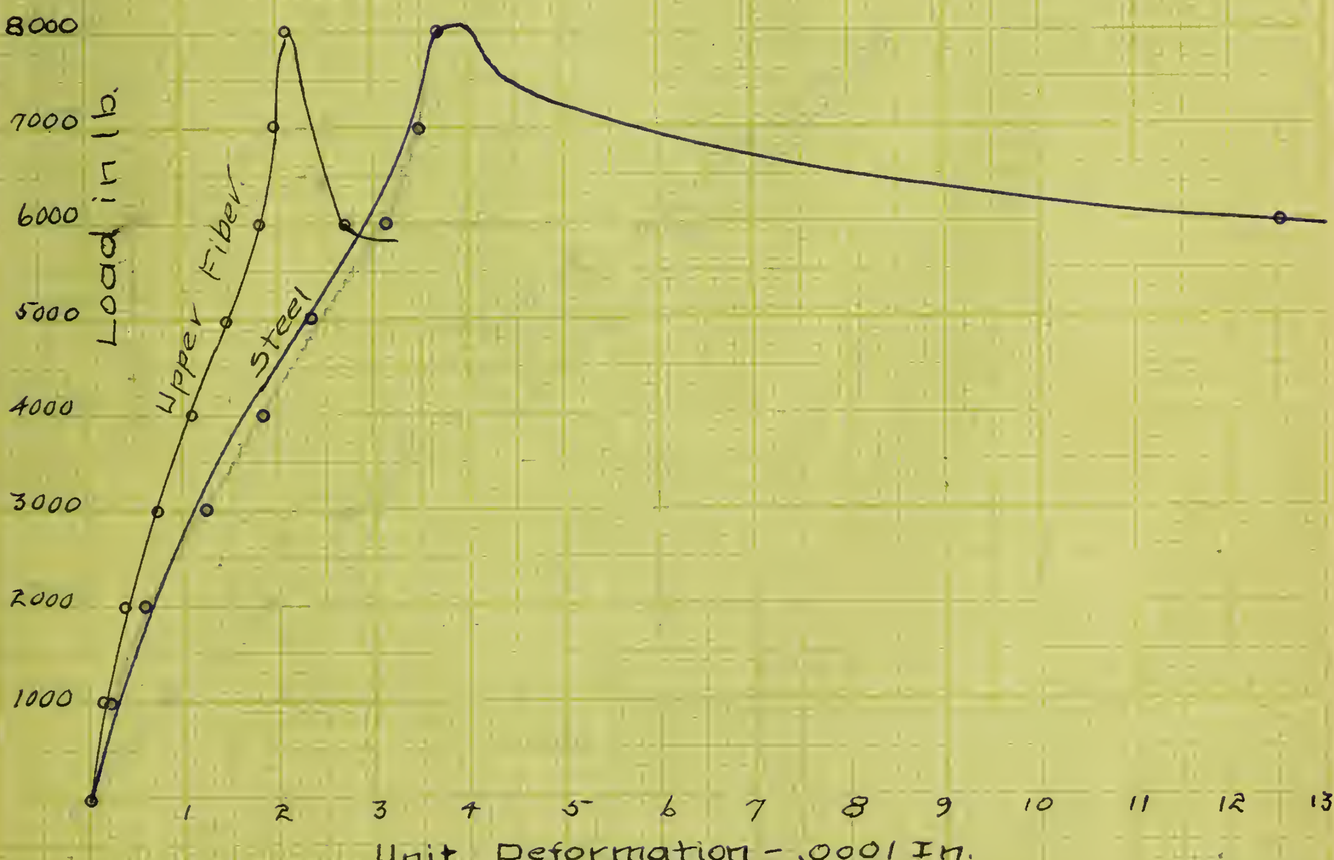
PLATE II.

Positions of Neutral Axis.



BEAM NO. 53.

Outside Extensometers.

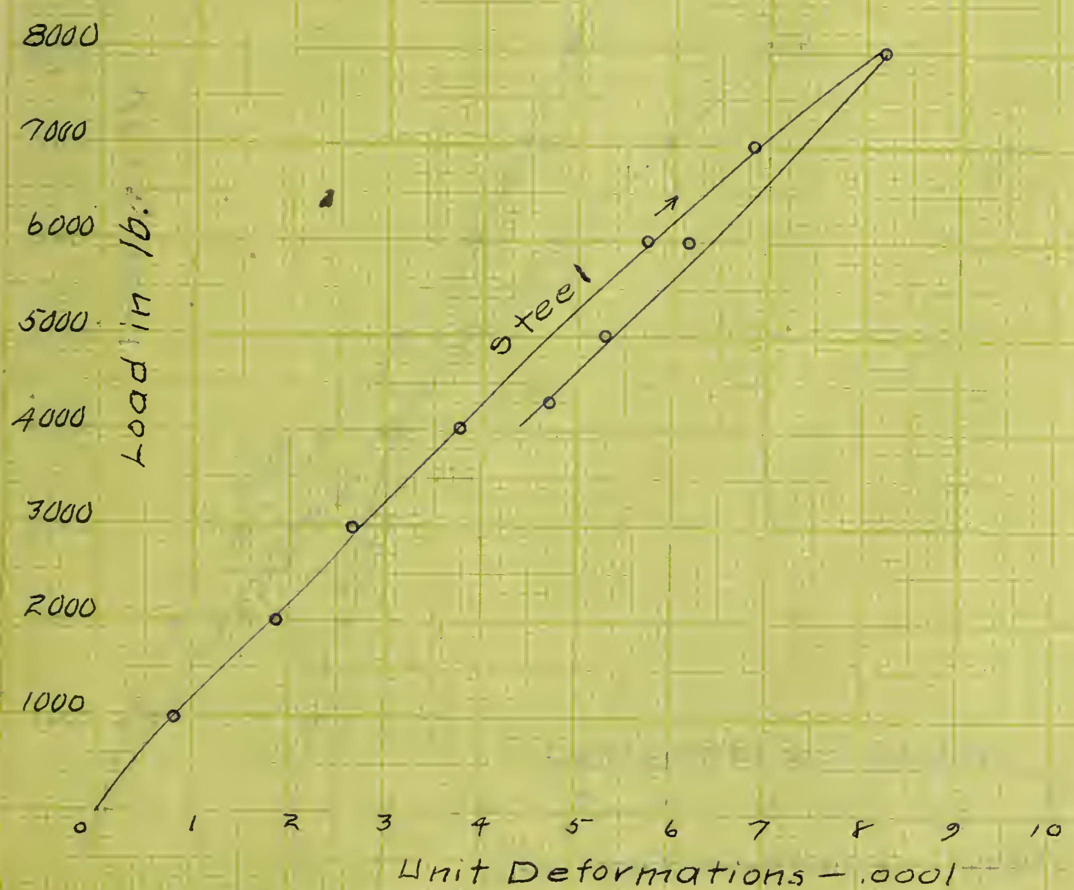


Abrams

PLATE 12.

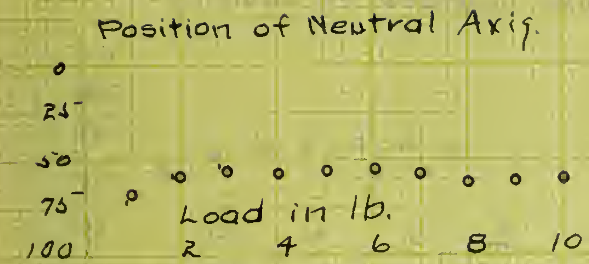
BEAM NO. 53.

Extensometers on Steel Rod.



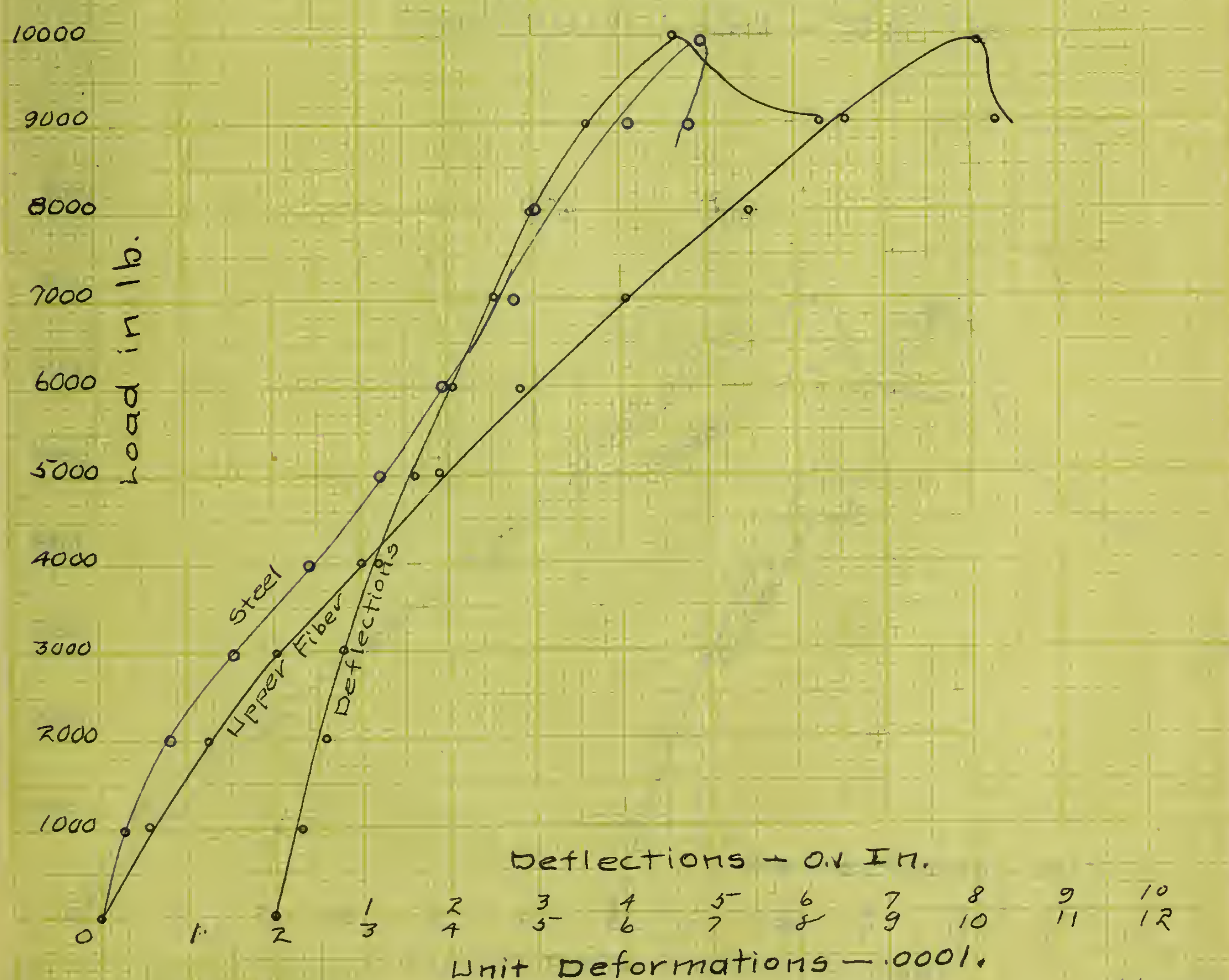
Abrams

PLATE 13.



BEAM NO. 55.

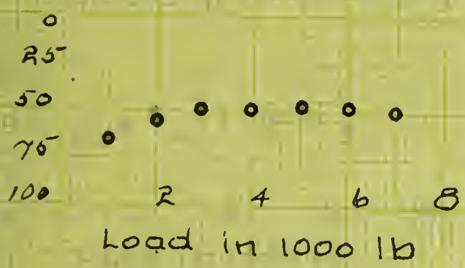
3 - 3/4 In. High Steel Rods.
Plain Reinforced.
Maximum Load — 9950 lb.



Abrams

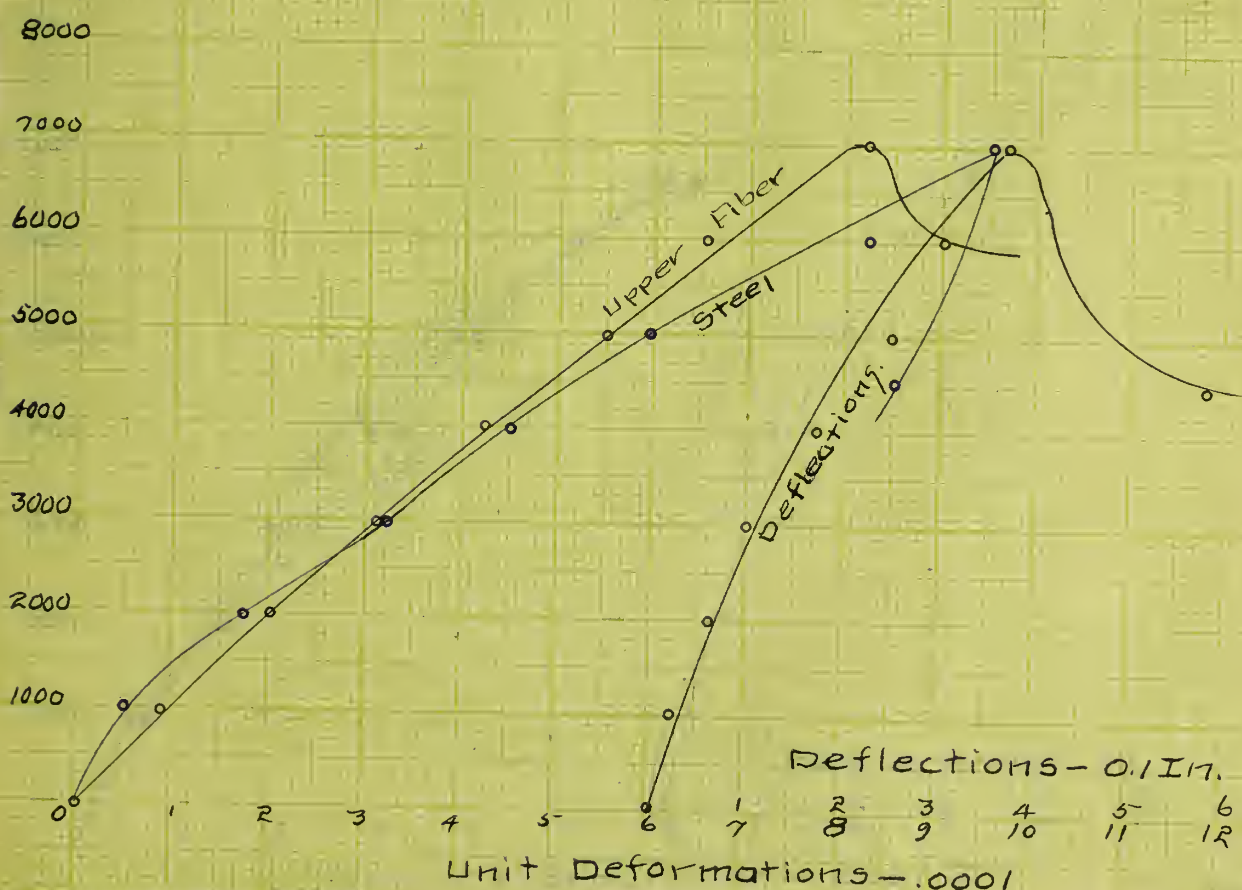
PLATE 14.

Positions of Neutral Axis.



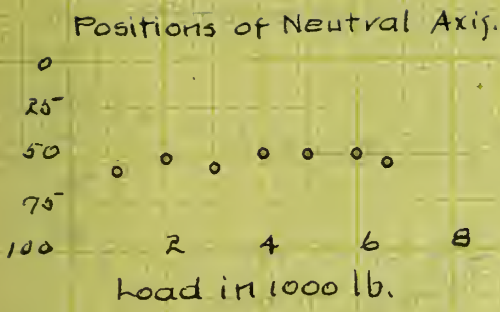
BEAM NO. 57.

2-3/4 In High Steel Rods.
Simple Reinforced.
Maximum Load - 7350 lb.



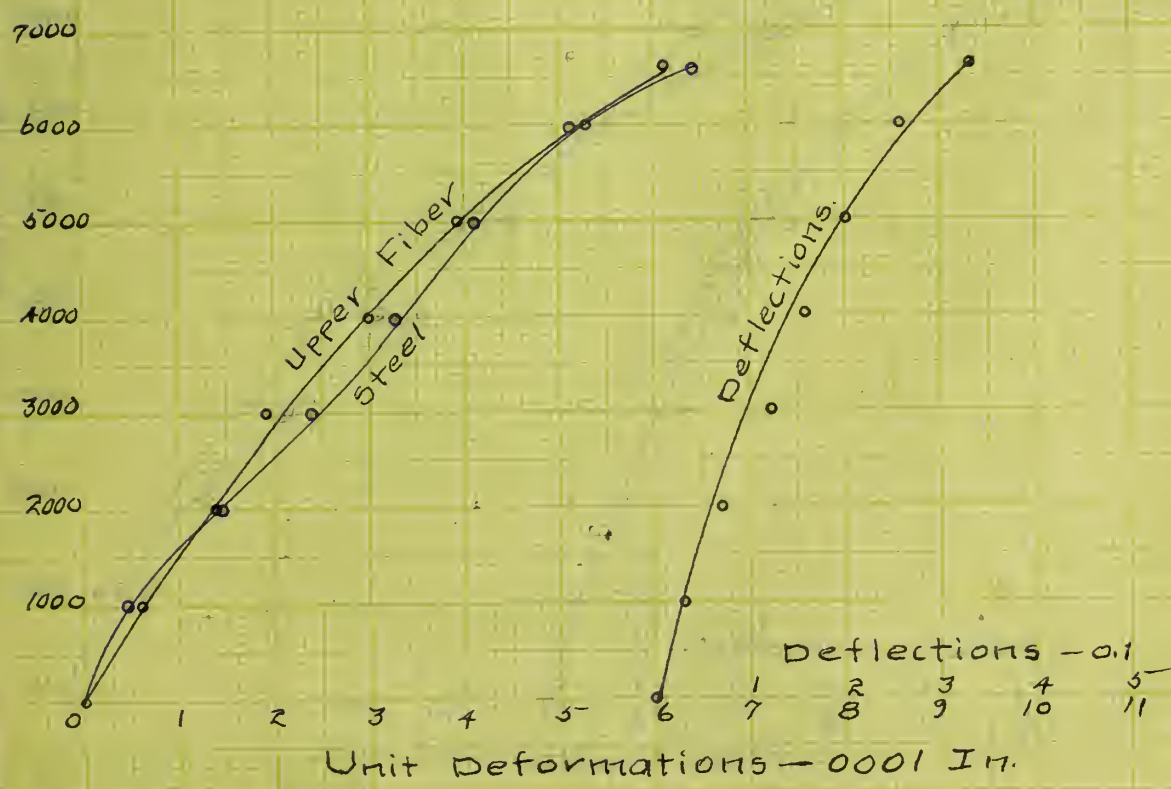
Abrams

PLATE 15



BEAM NO. 61.

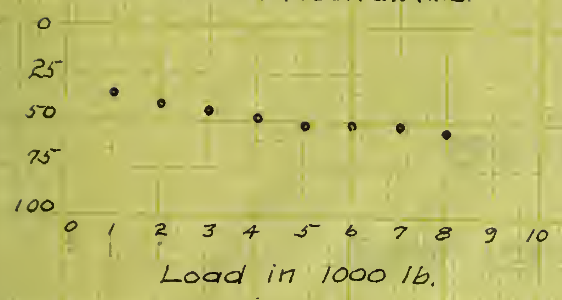
3-¾ In. High Steel Rods.
13 Tins in Middle.
Maximum Load; 6600 lb.



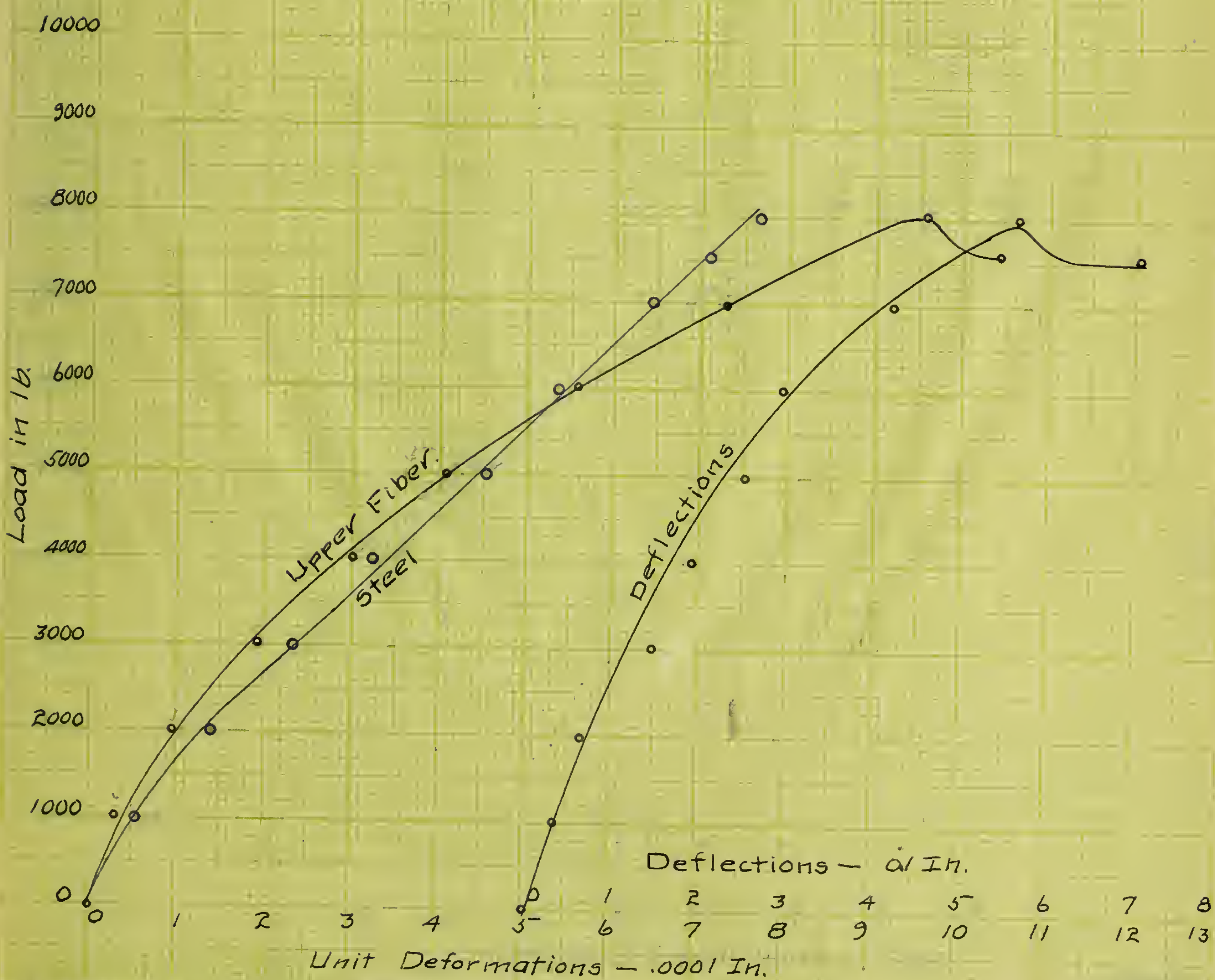
Abrams

PLATE 16.

Position of Neutral Axis.



BEAM NO. 62.
Extensometer Span, 42 In.
2-3/4 in Round steel Rods.
16 in Arch at Middle.
Maximum Load 8100 lb.



Abrams

PLATE 17.

BEAM NO. 62.

Extensometer on Steel Rod.

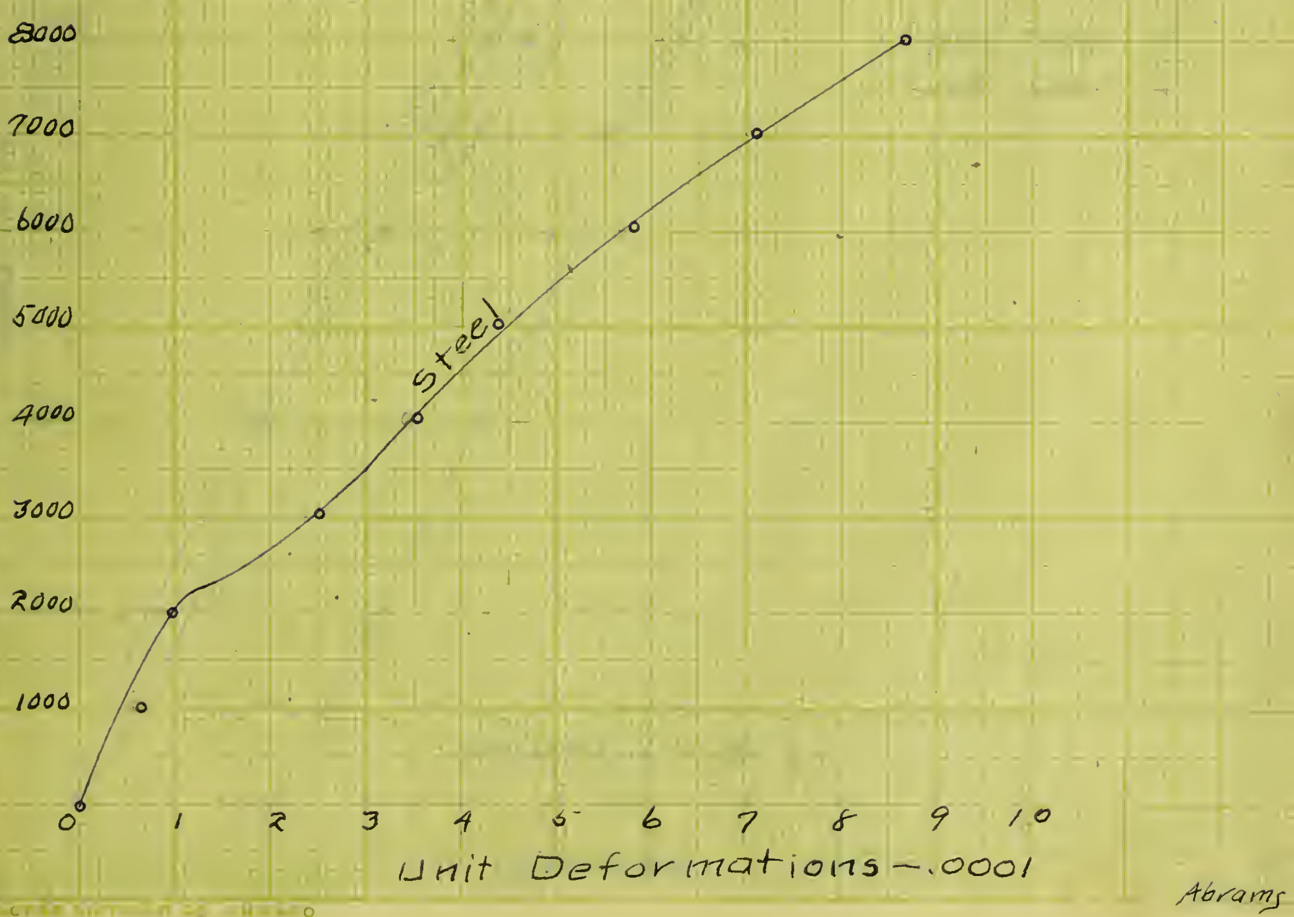


PLATE 18.

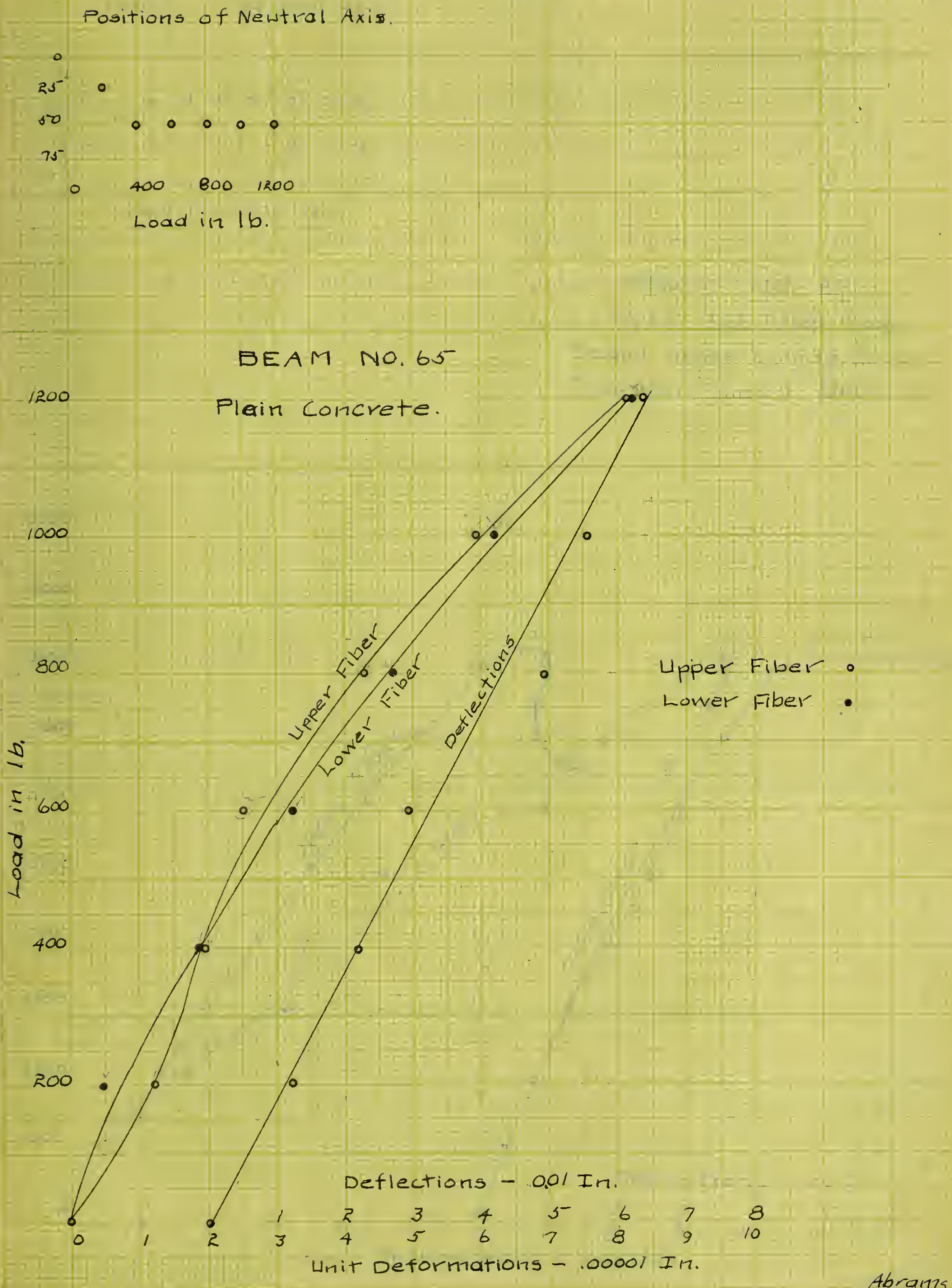
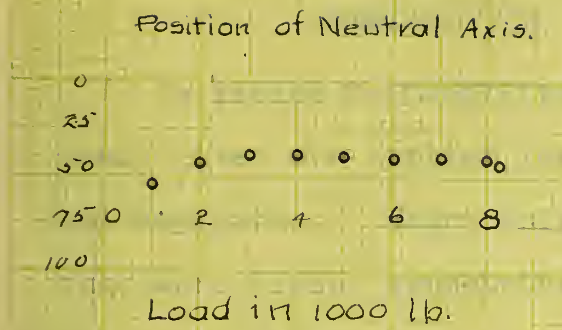
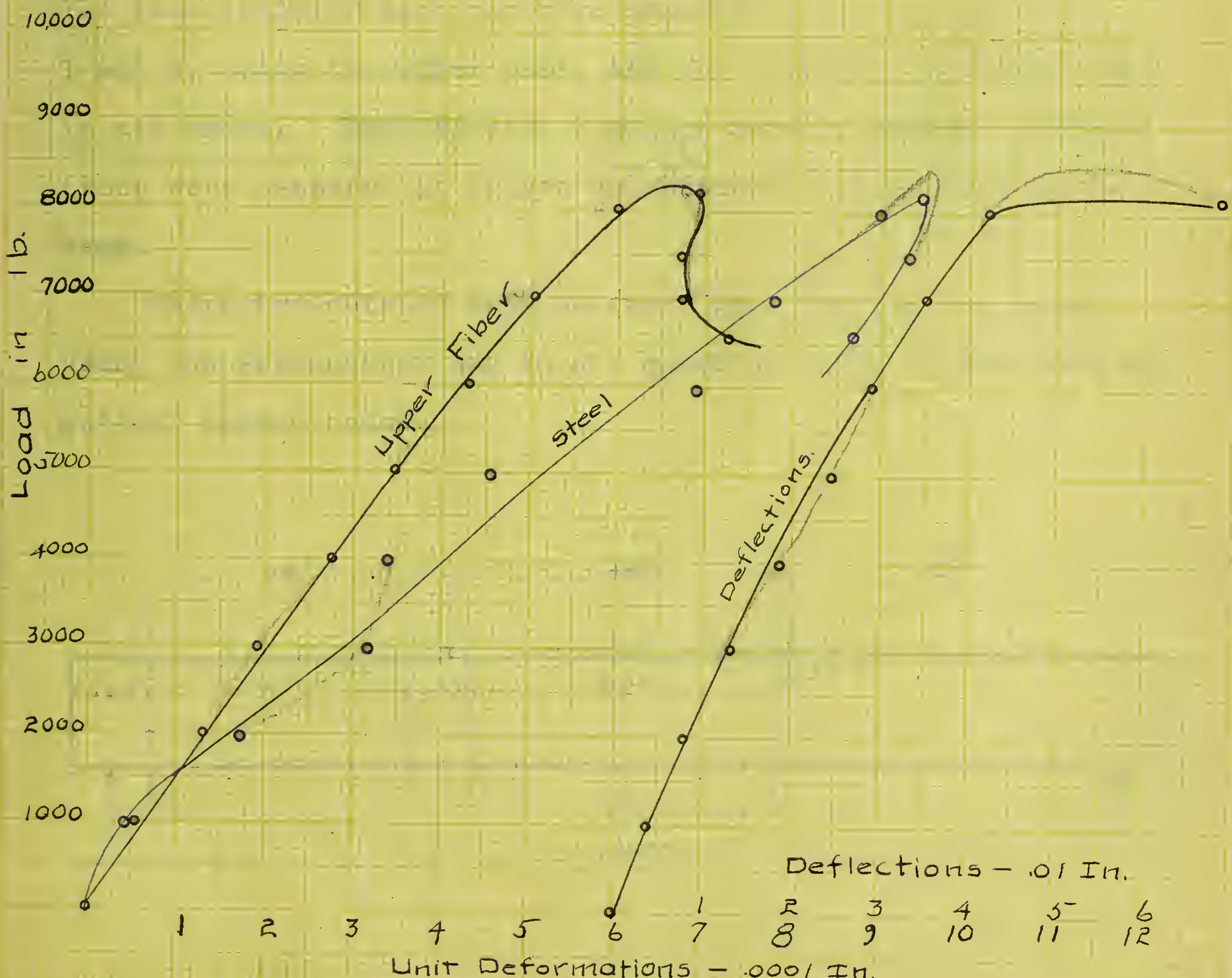

Positions of Neutral Axis.
0
25
50
75
0
400
800
1200
Load in lb.
BEAM NO. 65
Plain Concrete.
1200
1000
800
600
400
200
Load in lb.
Upper Fiber
Lower Fiber
Deflections
Upper Fiber o
Lower Fiber •
Deflections – 0.01 In.
1 2 3 4 5 6 7 8
0 1 2 3 4 5 6 7 8 9 10
Unit Deformations – .00001 In.
Abrams

PLATE 19.



BEAM NO. 67.
2 - 3/4 In. High Steel Rods.
Beam made upside down.
Maximum Load 8600 lb.

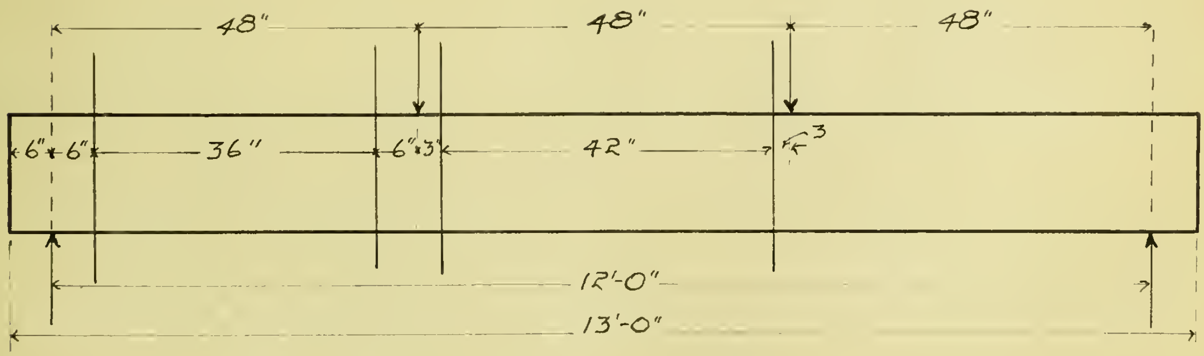


Abrams

EXPLANATION OF TABLES.

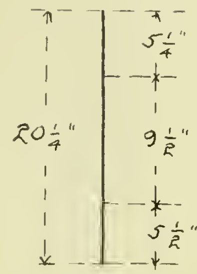
In Tables No. I to XVII pages 44 to 60 of original readings, loads given are applied loads, exclusive of weight of beams and apparatus. Where only one set of extensometers were used, they were placed symmetrically with respect to the middle of the beam, the span being given. Where two sets were used, one set was placed on middle, and one on outer third of beam, the latter in all cases having a span of 36 in., with the outer frame 6 in. from support, as shown in sketch below. These two sets have been designated in the tables and elsewhere, as Inside and Outside extensometers, respectively. The four dials of each set were numbered 1, 2, 3, and 4; No. 1 and 3, being the upper pair, and No. 2 and 4, the lower pair, in all cases. Extensometer readings were in inches. Deflections were measured in inches and meters at the middle of the beam.

Where two sets of extensometers were used on the same beam, the arrangement was in all cases as shown on the diagrammatical sketch below.



Where only one set of extensometers was used, the arrangement was as shown for inside set in figure above, except that span was sometimes changed to 54 in.

Outside



Inside.

Above sketches show dimensions of arms, distance between contact points, etc., for extensometer yokes.

BEAM NO. 49. 2 3/4 IN. RODS.

Inside Extensometer. Extensometer Span 42 in.

Load lb.	Extensometer Readings. 1	3	2	4	Deflection Readings Meters
0	.0006	.0000	.0000	.0015	.86420
1000	68	60	78	87	285
2000	136	121	158	165	200
3000	199	179	136	241	120
4000	269	248	330	332	86000
5000	351	325	433	435	85875
6000	446	418	550	552	765
7000	539	511	660	661	590
8000	634	606	766	764	445
9000	739	713	872	871	270
8000	702	673	811	804	335
7000	668	642	764	755	375
6000	615	590	691	680	475
5000	548	525	604	589	575
4000	489	466	526	509	690
3000	426	406	449	441	775
2000	357	338	364	345	880
1000	271	263	263	242	86005
0	187	184	162	154	125
0 *	0	0	0	0	125
1000	67	61	76	73	86030
2000	126	116	149	144	85925
3000	192	178	232	172	845
4000	251	244	314	306	740
5000	331	311	404	392	660
6000	389	378	493	479	420
7000	461	439	577	564	410
8000	527	505	661	649	330
9000	605	581	753	741	180
9500	657	627	802	791	120
10000	701	678	857	845	85030
10500	757	739	913	898	84870
11000	819	800	968	954	840
11300					

* Extensometers reset.

BEAM NO. 49. 2 3/4 IN. RODS.

Outside Extensometers. Extensometer Span 36 in.

Load lb.	Extensometer Readings 1	3	2	4	Deflection Readings Inches.
0	.5000	0	.5000	0	.88
1000	4982	.0035	4984	.0008	89
2000	4954	0050	4960	0029	92
3000	26	75	37	50	95
4000	4890	108	4907	85	1.00
5000	4840	155	4845	145	1 04
6000	4795	200	4791	190	1 09
7000	51	240	40	239	1 14
8000	4704	290	4677	300	1 19
9000	4651	343	4606	368	1 24
8000	66	327	26	351	1 21
7000	80	310	46	330	1 20
6000	4704	286	75	308	1 18
5000	39	253	4709	273	1 14
4000	69	220	41	241	1 10
3000	98	196	72	214	1 07
2000	4830	160	4809	183	1 02
1000	64	120	50	149	0.98
0	4900	95	85	118	91
0	*.5000	0	.5000	0	91
1000	4979	.0015	4982	.0018	93
2000	56	35	58	42	1.00
3000	23	63	29	70	1.02
4000	4890	91	4899	103	1.05
5000	55	121	65	134	1 10
6000	23	153	31	169	1 13
7000	4790	181	4800	203	1 17
8000	55	212	4764	239	1 21
9000	13	251	17	283	1 25
9500	4690	277	4685	314	1 28
10000	60	304	49	350	1 30
10500	21	341	4600	400	1 35
11000	4578	390	4537	464	1 37
11300					

* Extensometers reset.

 TABLE III.

BEAM NO. 49. 2 3/4 IN. RODS.

Riehle Extensometer on Steel Rod, Gage Distance 8 in.

Load lb.	Extensometer Readings A	Extensometer Readings B
0	.0227	.0388
1000	233	98
2000	240	405
3000	247	411
4000	255	417
5000	263	425
6000	271	431
7000	280	440
8000	288	449
9000	295	458
8000	290	448
7000	285	440
6000	278	434
5000	270	423
4000	263	418
3000	255	410
2000	250	401
1000	242	392
0	236	383
1000	241	393
2000	247	402
3000	253	410
4000	258	417
5000	266	425
6000	275	434
7000	281	440
8000	289	448
9000	296	457
9500	300	462
10000	304	465
10500	308	471
11000	413	474

TABLE IV.

BEAM NO. 51. 3 3/4 IN. RODS.

Inside Extensometers. Extensometer span 42 in.

Load lb.	Extensometer Readings. 1	3	2	4	Deflection Readings Inches.
0	0	0	0	0	3.56
1100	.0092	.0084	.0102	.0089	3.60
2000	167	158	175	158	3.62
3000	243	231	261	242	3.67
4000	320	307	340	297	3.70
5000	392	383	433	323	3 74
6000	468	459	522	396	3 78
7000	549	594	617	408	3 81
8000	638	632	707	424	3 87
9000	712	722	797	440	3 91
10000	800	820	887	443 * 180	3 96
11000	892	913	977	328	4 02
11800	983	1046	1000	435	4 20
11000	991	1102	1050	429	----

* New zero reading taken here.

BEAM NO. 51. 3 3/4 IN. RODS.

Outside Extensometers. Extensometer Span 36 in.

Load	Extensometer Readings.				Deflection Readings
lb.	1	3	2	4	Meters
0	.4385	.0200	.1400	.0000	.87755
1100	.4368	.0222	.1390	.0016	.87670
2000	350	238	1372	24	580
3000	270	260	55	48	480
4000	298	286	33	67	350
5000	267	814	1299	92	265
6000	233	344	80	119	125
7000	199	377	56	150	87040
8000	170	410	24	179	86895
9000	141	440	1202	209	775
10000	118	469	1182	230	625
11000	3910	492	1169	245	440
11800	3908	492	1169	249	86015
11000	3908	492	1179	250	85700
7100	----	----	----	----	84540

TABLE VI.

BEAM NO. 52. 3 3/4 IN. RODS.

Inside Extensometers. Extensometer Span 42 in.

Load lb.	Extensometer Readings. 1	3	2	4	Deflection Readings Inches
0	0000	0000	0000	0000	1.55
1000	54	46	52	50	58
2000	105	101	120	117	59
3000	172	164	190	195	61
4000	232	229	259	267	65
5000	285	291	333	346	67
6000	352	258	404	418	72
7000	429	436	475	493	77
8000	504	510	550	569	81
9000	589	597	633	654	85
10000	676	685	713	742	90
11000	772	783	802	835	96
12000	877	890	898	934	2.01
13000	993	1007	998	1038	07
14000	1188	1106	1114	1152	17
14970	1339	1366	1258	1290	37

BEAM NO. 52. 3 3/4 in. RODS.

Outside Extensometers Extensometer Span 36 in.

Load	Extensometer Readings				Deflection
lb.	1	3	2	4	Meters
0	.5000	.000	.5000	.000	.88510
1000	.4981	.0014	.4996	.000	460
2000	4956	36	4979	18	385
3000	4927	65	4958	38	300
4000	4896	80	4932	60	210
5000	4866	115	4909	85	105
6000	4832	149	4878	111	88000
7000	4795	192	4847	139	87880
8000	4768	195	4830	158	750
9000	4744	220	4823	170	650
10000	4736	226	4823	174	525
11000	4729	230	4832	176	375
12000	4725	235	4839	178	210
13000	4720	237	4855	178	87025
14000	4764	240	4885	50	86745
14970	.0120	.0200	.4970	.4250	.86265

BEAM NO. 53. 2 3/4 IN. RODS.

Inside Extensometer Span 42 in. Riehle Extensometer Span 8 in.

Load	E x t e n s o m e t e r			R e a d i n g s .	
lb.	1	3	2	4	A	B
0	.0013	.0009	.0005	.0015	.0433	.0444
1000	92	65	57	109	441	449
2000	189	148	325	192	451	455
3000	282	233	505	287	460	459
4000	392	332	704	401	469	468
5000	511	437	820	519	483	479
6000	441	555	1145	643	488	480
7000	788	690	1383	774	497	490
8000	960	849	1652	921	499	509
6000	1094	983	1560	880	480	495
4320	1291	1542	1733	877	468	484

BEAM NO. 53. 2 3/4 IN. RODS.

Outside Extensometers. Extensometer Span 36 in.

Load	Extensometer Readings				Deflection Readings	
lb.	1	3	2	4	Inches	Meters
0	.4843	.0035	.4650	.0050	1.35	.88485
1000	24	51	32	50	39	425
2000	4794	80	4600	44	42	295
3000	50	120	4555	54	46	190
4000	4704	163	4510	91	51	88045
5000	4660	202	4468	133	57	87870
6000	4608	251	4410	185	64	690
7000	4595	275	4385	190	71	515
8000	93	291	65	191	82	270
6000	4320	684	3810	850	2.20	86220
4300	----	---	----	---	2.81	84725

BEAM NO. 55.

3 Rods---Simple Reinforced. Extensometer Span 42".

Load	Extensometer	Readings.			Deflection.	
lb.	1	3	2	4	In.	Meters.
00	.0047	.0016	.0047	.0075	0.93	.90965
1000	84	54	80	103	96	930
2000	140	104	133	157	99	855
3000	205	165	201	218	1.01	760
4000	285	237	280	289	05	655
5000	361	306	353	360	09	545
6000	442	384	427	437	13	415
7000	530	468	510	517	18	270
8000	615	563	588	584	23	145
9000	710	564	673	670	29	89960
9950	810	757	759	755	39	695
9000	820	774	743	740	56	230
5400	---	---	---	---	----	88295

Vertical crack 5" high appears 4" outside of north load, at 8000 lb. Above crack is 7" high at maximum load, 9950 lb.

Crushing begins just outside of north load, and a horizontal crack appears along plane of rods, where failure occurs.

BEAM NO. 56. 2 3/4 IN. RODS.

Rods Wrapped in oiled paper. Extensometer Span 54 inches.

Load	Extensometer Readings.				Deflection Readings.	
lb.	1	3	2	4	Inches	Meters
0	.0020	.0100	.0010	.0025	1.73	.8952
600	1665	1558	4378	4665	2.52	8748
660	3170	2510	8900	8650	3.27	8572
860	4250	3640	1.1900	1.1640	3.80	8433

BEAM NO. 57. 2 3/4 IN. RODS.

Extensometer Span 42 In.

Load	Extensometer Readings				Deflection Readings	
lb	1	3	2	4	Inches	Meters
0	.0045	.0059	.0126	.0031	1.08	.91275
1000	135	100	173	94	10	205
2000	230	185	283	197	14	91000
3000	330	278	402	319	18	90980
4000	429	364	509	436	25	785
5000	544	463	625	570	33	620
6000	652	564	737	700	38	430
7000	793	676	853	847	46	215
7350	---	---	---	---	----	-----
4500	745	602	757	750	1.68	89700

BEAM NO. 61. 3 3/4 IN. RODS.

Extensometer Span 54 in.

Load lb.	Extensometer Readings. 1	3	2	4	Deflection Readings Inches
0	.0004	.0034	.0013	.0007	.85725
1000	60	92	53	75	655
2000	150	176	160	180	545
3000	234	259	258	280	435
4000	332	354	368	383	330
5000	430	450	476	485	215
6000	536	559	593	611	85085
6600	678	600	633	649	84890

BEAM NO. 62. 2 3/4 IN. RODS.

Extensometer Span 42 in.

Load	Extensometer Readings				Deflection Readings
lb.	1	3	2	4	Meters
0	.0045	.0004	.0002	.0050	.8600
1000	34	71	102	38	8591
2000	93	125	173	102	84
3000	178	198	267	183	65
4000	270	276	359	268	53
5000	314	366	459	355	34
6000	478	464	572	452	25
7000	610	588	688	552	8493
8000	782	739	836	674	58
8100	---	---	---	----	---
7600	810	761	836	671	8425

BEAM NO. 62. 2 3/4 IN. RODS.

Riehle Extensometer on Steel Rod, Gage Distance 8 In.

Load Pounds	Extensometer Readings.	
	A	B
0	.0035	.0066
1000	37	73
2000	35	80
3000	35	104
4000	43	112
5000	52	117
6000	64	127
7000	73	140
8000	85	152
7600	83	151

BEAM NO. 65. PLAIN CONCRETE.

Extensometer Span 42 In.

Load lb.	Extensometer Readings 1	3	2	4	Deflection Readings Meters
0	.0021	.0002	.0000	.0004	.84000
200	23	10	3	17	83970
400	34	18	12	21	45
600	44	28	22	30	25
800	59	38	35	41	875
1000	70	48	46	51	860
1200	88	63	63	68	845
1260	--	--	--	--	---

BEAM NO. 67. 2 3/4 IN. RODS.

Extensometer Span 42 In.

Load	Extensometer Readings				Deflection Readings
lb.	1	3	2	4	Meters
0	.0010	.0001	.0014	.0015	.86000
1000	54	41	55	68	85915
2000	125	107	165	154	810
3000	205	173	274	255	660
4000	281	237	378	354	535
5000	363	309	482	460	385
6000	432	369	565	543	275
7000	503	432	652	637	126
8000	586	507	752	739	84930
8600	---	---	---	---	-----
8200	660	554	805	790	84270
7500	649	544	784	778	150
6600	680	534	778	735	82295